Bachelor Thesis

Bachelor's degree in Industrial Technology Engineering (GETI)

Design and prototyping of an automatic quoting tool for domestic solar systems

REPORT

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Abstract

This project revolves around the creation of a tool that is capable of sizing solar systems based on a short and simple interaction with its users. Photovoltaic, thermal and hybrid solar technologies are used for the designed system to be able to cover the highest possible percentage of the total energy demand of a household. The tool also pursues maximizing the profit that can be obtained from the system by optimally combining the aforementioned technologies.

This report explains how the final web application has been built. Firstly, a brief market study was conducted to see what other already available tools were like, and if any features were (not) to be adopted from them. Secondly, some research was done on solar energy in order to be able to devise a calculation process that met the requirements of the project. Once this process was determined, the tool was implemented as a single-page web application using mainly the JavaScript programming language and the user interface was designed. Finally, a usage example of the tool was made in order to assess the outcome and compare it to what the initially evaluated tools had to offer.

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Listings

Glossary

API: Application Programming Interface

CPI: Consumer Price Index

DHW: Domestic Hot Water

EROI: Energy Return On Investment

ESTIF: European Solar Thermal Industry Federation

FPC: Flat Plate Collector

IRR: Internal Rate of Return

NPV: Net Present Value

OM: Operation and Maintenance

PSH: Peak Sun Hours

PV: Photovoltaic

PVT: Photovoltaic-thermal

PVGIS: Photovoltaic Geographical Information System

SPA: Single-page Application

STC: Standard Test Conditions

Chapter 1

Preface

1.1 Origin of the project

The project originates from the inital talks with my tutor, Alba Ramos Cabal, who has a deep understanding of solar energy systems coming from her scientific work. In the early stages, this project's aim was to build a quoting tool for solar PV systems alone. However, Alba brought thermal and hybrid solar energy to the table and her suggestion ended up changing the original idea. Upon the realization that the profitability of each of these solar technologies highly depends on the weather and energy needs of the end user, the project has ended up consisting in the development of a tool that not only designs a solar system, but also does so with the aim of finding the most profitable option for a particular location and energy needs.

1.2 Motivation

In my particular case, the main motivation for studying industrial engineering was to lay the technical foundations for a future career in renewable energy. In line with that, the main personal motivation behind this bachelor's thesis is to keep expanding my knowledge in this field as well as to develop something entirely new on my own.

Another aspect of this thesis' motivation is trying to propose an alternative to the current solar energy market trends. Although thermal energy is being widely installed across new buildings because of the 2006 spanish building code [1], solar photovoltaics (PV) have taken the residential market by storm and are the option that most household owners tend to go for. This is comprehensible because PV technology makes for a great investment. Nevertheless, it is a fact that investments in solar thermal and hybrid panels may outperform those in PV panels under certain conditions.

With prospectives of PV self consumption installations nearing 300-400 MW per year in Spain [2], the opportunity is there to help those installing them take more profitable decisions or even convince them to make a greater positive impact on the environment by coupling both PV and thermal technologies.

Chapter 2

Introduction

The present project revolves around the creation of a domestic solar system quoting tool that deals with different types of solar energy technologies and is able to output —upon combining them— the most profitable solar system for different scenarios. What is special about this project, is that it focuses on embracing thermal and hybrid solar energy as part of the solution for household owners that wish to make the switch to solar energy.

But why include thermal and hybrid panels when the domestic solar market is clearly driven by PV technologies? According to the International Energy Agency, approximately half of the world's usage of energy is in the form of heat [3] and, to put it into this project's perspective, space and water heating account for the 78.9% of the total energy consumption within EU-28 households. Therefore, it can be said that solar thermal energy, especially in its distributed form, has a huge potential insofar as it is capable to satisfy this kind of energy needs in a clean and renewable way.

As mentioned earlier, the residential market of solar energy has been dominated by PV technology due to its rapidly increasing competitiveness over the last few years. By nature, though, the profitability of a solar energy system does not only depend on the employed technology, but also varies in accordance with different parameters like solar irradiance or satisfied energy demand, for example. These variations can provoke, under certain circumstances, that either thermal or hybrid panels outperform PV panels in economic terms. The tool will recognise these situations and aid the user in taking the smartest possible decision while also promoting the installation of solar thermal technologies alongside PV systems when possible.

2.1 Objectives

The main objective of this bachelor's thesis is to create what can be considered a first iteration of this tool. The tool has to be able to output a viable solar system according to certain input variables provided by the user. Broadly speaking, this main objective can be divided into two sub-objectives:

1. **To devise a calculation process for the tool**. This, in turn, includes two main goals:

   - To identify the necessary set of variables and how they will be used to size the solar systems and calculate their profitability.

   - To ideate an algorithm capable of using every possible combination of these input variables in order to output the best solution.

2. **To build the tool**. This second objective also includes two sub-goals:

   - To design an easy-to-use user interface.

   - To achieve a working prototype.

2.2 Scope of the project

This project consists on building something new from scratch. Correspondingly, the scope of this thesis includes covering this process step by step from a brief market study to the creation of the actual tool.

Perhaps it is important to make clear that while the complete planning, ideation and prototyping of the tool fall within reach, the level of complexity that this last stage will be able to achieve will highly depend on time availability. Therefore, the scope of this project includes a working prototype that is able to perform according to plan, but excludes any additional activities like fine-tuning the design, for example. These kind of activities will be tackled if extra time is available.

Chapter 3

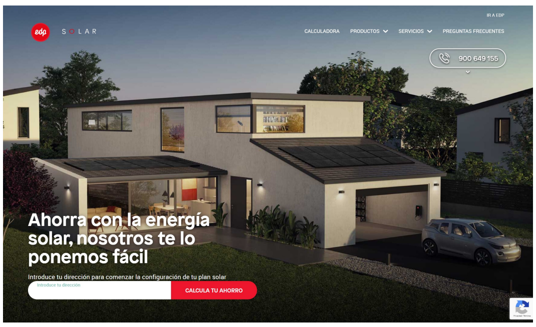
Market study

To get an idea of what the state of the art is like in terms of online solar system planning and quoting, a market study has been conducted. This has consisted on the evaluation of 4 different websites that allow their customers to plan out their solar systems online by giving some key information. Although all of these sites try to reach the same goals, it is interesting to observe the different user experiences that they make use of, as well as the differences in the information that they require to make the calculations.

3.1 Repsol Solify and EDP Solar configurators

The first tools that are going to be explored are *Repsol Solify* and *EDP Solar*. These two online tools are grouped together under the same subsection because they share a lot of similarities. They have been chosen because of their connection with two reference companies in the energy industry that surely have the average consumer in mind. As can be deduced from the following paragraphs, they may not offer the most exact calculation methods but they do provide an excellent user experience.

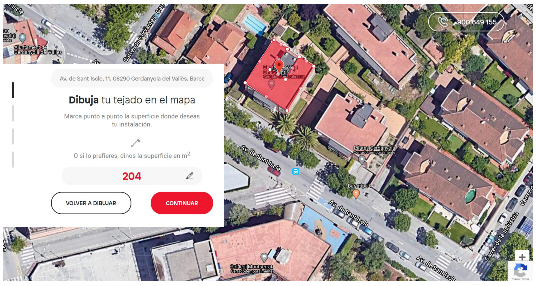
The user flow is quite simple in both cases. Upon entering their homepage, both tools invite the customers to write their home adresses in a searchbar. They then proceed to use this information to bring them to a map where they are allowed to easily draw their roofs.



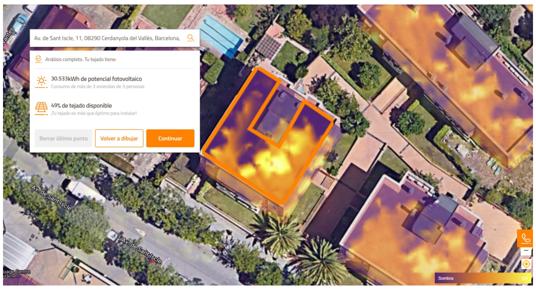
(a) EDP Solar: Homepage

(b) Repsol Solify: Homepage

Figure 3.1: Homepages of EDP Solar and Repsol Solify



(a) EDP Solar: Map



(b) Repsol Solify: Map

Figure 3.2: Maps of EDP Solar and Repsol Solify

Up until this point, both tools have obtained an approximation of the roof space that is available for the project with the use of Leaflet, which is a Javascript library that allows using interactive maps within websites. They have also obtained the user's location, which they can later use to get any meteorological data by querying external databases.

The two platforms then proceed to ask the user to answer three short questions with the aim of getting to know their needs. The first question is the same in both cases; whether the system is to be installed in a domestic or business setting. They also ask an identical second question by requesting the user to indicate their monthly electricity bill expenditure. Lastly, the two third questions differ one from each other. EDP wants to know if the user resides in a housing estate, while Solify asks for the periods of the day that tend to have higher electricity demands.

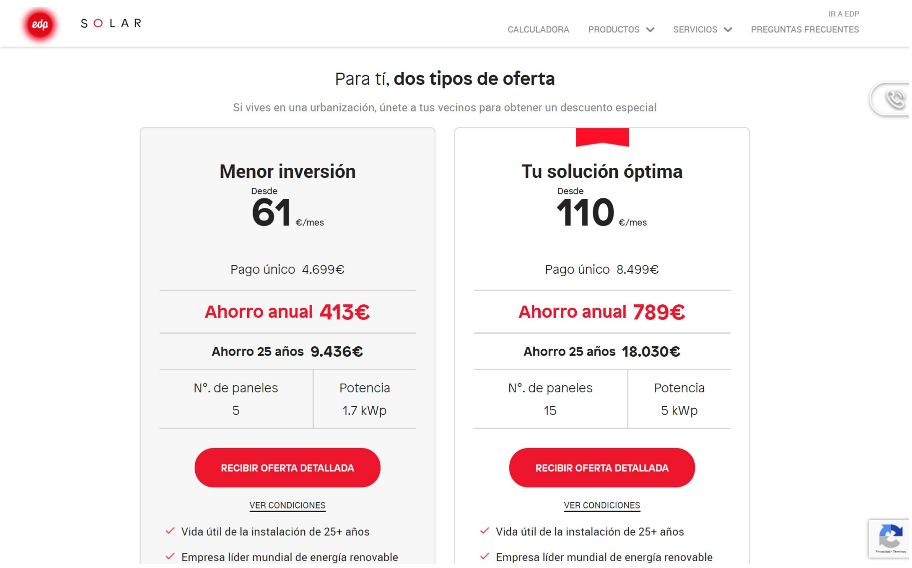
(a) EDP Solar: Questions

(b) Repsol Solify: Questions

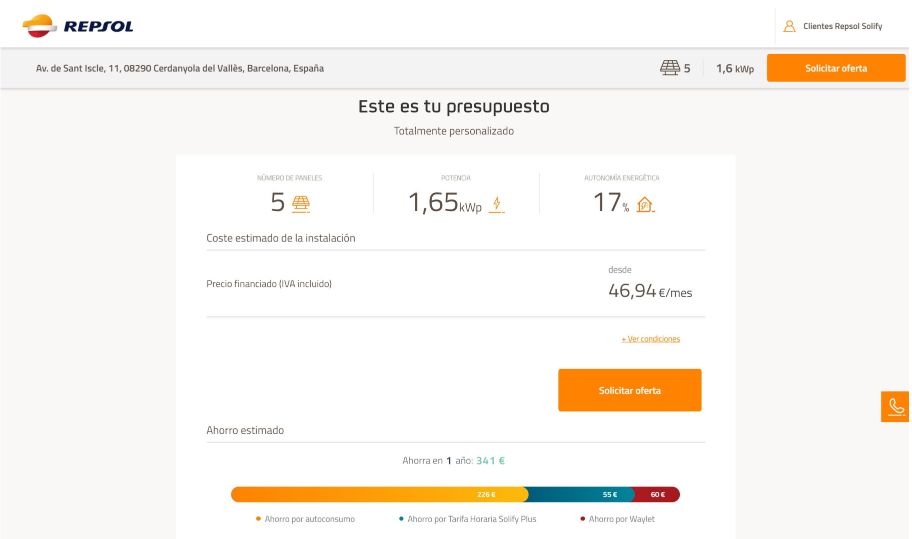
Figure 3.3: Demand related questions of EDP Solar and Solify

It is difficult to know exactly what each piece of information is going to be used for. However, one may conclude that the two platforms are going after an estimation of the electricity demand and that, together with the meteorological data that they can obtain from step one, they are able to devise viable solar systems. Once all the answers to these questions have been introduced, the users are shown their personalized output.

Excluding some subtleties, the two outputs contain basically the same information, as seen in figure 3.4. The user gets to know how big the solar system is going to be in power terms, as well as the pricing and the savings that come with it. Additionally, the EDP Solar tool offers two options at different price points. One is the advised minimal investment and the other one is labeled as the optimal solution.



(a) EDP Solar: Output



(b) Repsol Solify: Output

Figure 3.4: Outputs of EDP Solar and Solify

3.2 Zolar

The third tool that will be analyzed is from the German company Zolar. This company was a pioneer in terms of online solar system quoting and what is interesting about their tool is that, in contrast with the ones that were presented earlier, the process from quote to installation happens entirely online. The other tools' prices were subject to a later evaluation of the project but, unlike those, Zolar does not give the customers an instant quote. Instead, it takes some time to process their data and send them a full assessment that is ready to be accepted and includes different options, profit simulations and a 3D model of the system among other things.

The first step of the Zolar quoting tool entails choosing between a solar system with or without batteries.

Figure 3.5: First step of Zolar

After this first step, the functioning is very similar to what has been seen in the previous platforms; users are asked to give information about how many people live in the house, the inclination of their roof and their location. As previously mentioned, there is no immediate output and, after a few days, Zolar sends a full report together with an offer. It is interesting to see that instead of using the electricity bill, Zolar makes use of the number of dwellers to estimate electricity demand. They also introduce the roof inclination metric, which could be used to either calculate additional fixing and mounting costs or to compute the separation between panel rows, as different inclinations will imply differences in panel-provoked shading.

3.3 Sunny Design

Lastly, the tool Sunny Design from the company SMA has been analyzed. This is a full-fledged solar system design tool that is oriented towards solar energy professionals and boasts a very wide range of options. It also has a quick configuration mode, which is the one that has been observed.

The inital step, similarly to what has been seen so far, consists on setting a project name and a location. Additionally, the tool also asks for the inverter grid connection to subsequently select compatible inverters. Although this may not be a problematic question for a lot of people, it is worth pointing out that many other technical questions are posed after this step and throughout the whole Sunny Design user flow.

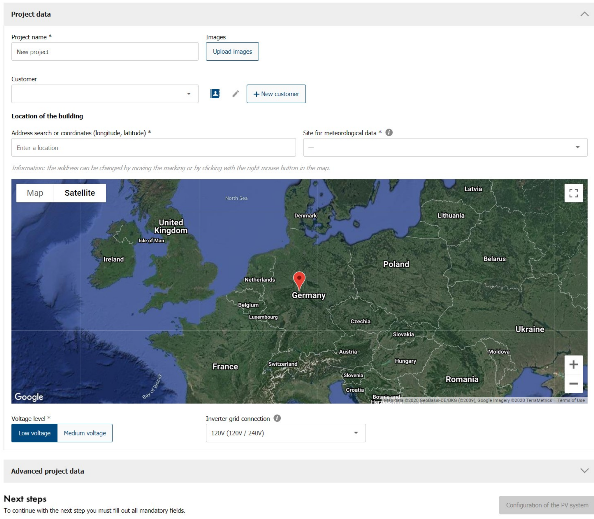
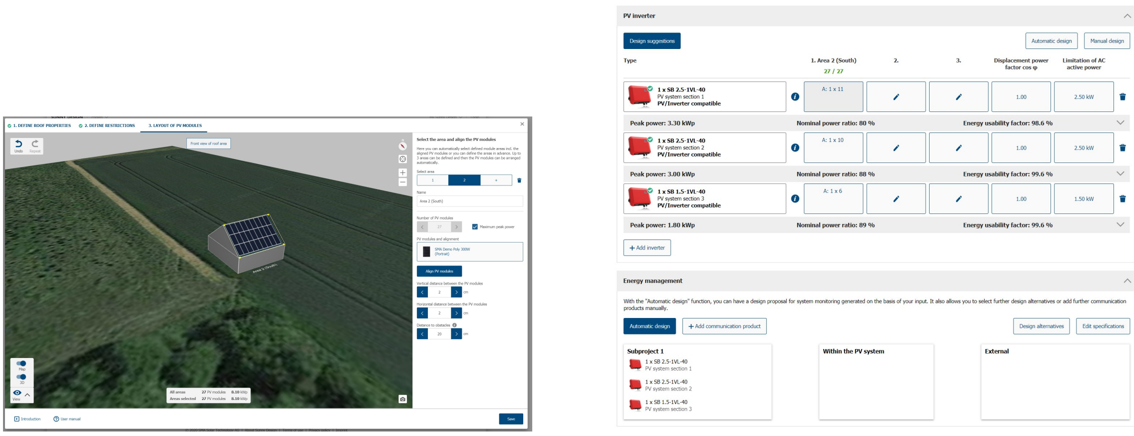


Figure 3.6: First step of Sunny Design

During the second step, a very elegant way of laying out the PV panels is presented. It is possible to generate a 3D model of a house that accurately resembles reality in terms of size and orientation and to position the array of panels over its roof. Once the array is positioned, Sunny Design suggests a viable combination of inverters and allows the customer to select any desired communication systems.



(a) Sunny Design: 3D simulation

(b) Sunny Design: Inverter and communications

Figure 3.7: Second and third steps of Sunny Design

After these second and third steps, the tool offers a detailed profitability analysis that can be customized for each customer's specific costs (€/kWp) and annual fixed costs. It also allows for the inclusion of financing models and the modification of expected electricity price scenarios.

Overall, Sunny Design can be graded as the best and most exact tool that has been examined so far, but it can also be said that making use of it can be difficult and counterproductive. The average consumer will find it challenging to deal with some steps of the process and can get to a wrong configuration if the tool ends up not being used correctly.

3.4 Findings

The four tools that were analyzed in this chapter achieve different accuracy degrees and do so through different ways of interacting with the client. It is noticeable that EDP, Repsol and Zolar run web applications that are really pointed towards the average consumer while SMA has a much more detail-oriented tool.

The aim of this project is to be as consumer friendly as possible. Therefore, it is concluded that the tool that will be developed needs to resemble the ones that were explored in subsections 3.1 and 3.2. However, it is also observed that these tools do not take into account some variables that are essential in solar system design like roof orientation, for example. Apart from this, it is also worth mentioning that, thanks to Repsol and EDP being such enormous corporations in the energy industry, they may be able to rely on huge databases that allow them to do things like accurately estimating electricity demand based on consumers' electricity bills. Zolar is a much smaller company and approaches this issue by asking for the number of dwellers in the house, so it will be precisely variables like this one that will be explored in further sections in order to be able to make this kind of estimations.

Chapter 4

Proposed solution

The different solutions presented earlier in chapter 3 show some viable options of how tools of this kind may be implemented and give a general idea of what the one we are aiming for should be like. However, because we also need to take into account solar thermal and solar hybrid technologies, which the other tools do not, a new approach should be devised.

This new approach takes into account the possibility of installing any of the three types of solar energy technologies and outputs the optimal combination of panels that maximizes the Internal Return Rate (IRR) of the investment for any given area. This section describes the proposed solution from a theoretical point of view.

4.1 Preliminary remarks

Before starting to introduce the proposed solution it is important to make some preliminary remarks. The most important remark to be made is possibly that, due to the nature of some of the estimations and calculations, the present tool will work well across locations within mainland Spain. As we move away from the 41º latitude mark, however, estimations are expected to become increasingly inaccurate. This could be fixed in future versions of the tool.

The other remark to be made is that another small market study has been carried out in order to select the panels of each technology that the tool will be dealing with. This panel selection is detailed in the following three subsections.

4.1.1 PV Panel selection

Different types of solar cell technologies can be used to generate electricity and many different panels are available nowadays with varying characteristics. Efficiency, for example, varies across technologies as depicted in figure 4.1 [4].

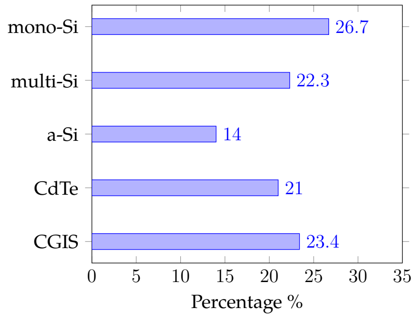


Figure 4.1: Record lab efficiencies for different PV technologies

With a record lab efficiency of 26.7%, mono-Si technology is the most competitive nowadays in terms of performance, which translates into a dominant 69% market share [5]. Although its utilization also comes with many drawbacks, like the use of highly toxic materials when compared to amorphous silicon, their outstanding efficiency levels cannot be overseen.

Therefore, mono-Si has been considered to be the technology that best fits this project's needs and a further analysis has been carried out among the best mono-Si PV panels to make a final decision. The website energysage.com **energysage** provides information on countless PV panel models and has an option to filter them based on specific criteria. A total of 10 mono-Si panels have been selected for this comparison, 5 have been picked from the best ones after filtering by efficiency and, similarly, another 5 have been picked from the most popular ones as of March 2020.

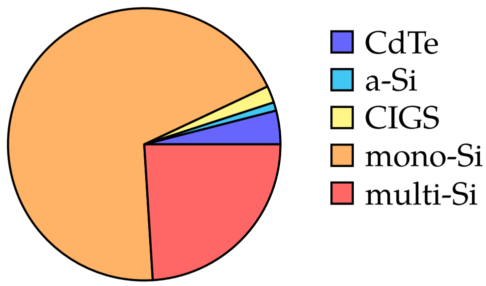


Figure 4.2: PV market distribution

Table 4.1: Analysis of various PV panels

Panel Name	**Nominal Power** $[W]$	**Dimensions** $[mm]$	**Area** $[m^2]$	Wp/m^2	€$/Wp$	**Ratio**
REC Alpha REC370AA	370	1721 x 1016	1.75	211.43	2.52	83.90
LG NeON 2 LG350N1C-V5	350	1686 x 1016	1.71	204.68	2.74	74.70
Panasonic HIT VBHN330SA17	330	1590 x 1053	1.67	197.61	2.71	72.92
Solaria PowerXT-370R-PD	370	1621 x 1116	1.81	204.42	2.82	72.49
Sunpower X-Series X22-370	370	1558 x 1046	1.63	226.99	3.26	69.63
Silfab SLA-M SLA-310M	310	1650 x 990	1.63	190.18	2.74	69.41
LG NeON R LG375Q1C-V5	375	1700 x 1016	1.72	218.02	3.15	69.21
REC Alpha Black REC360AA	360	1721 x 1016	1.75	205.71	3.01	68.34
Sunpower E-series SPR-E20-327	327	1558 x 1046	1.63	200.61	3.04	65.99
Panasonic HIT+ VBHN340SA17	340	1590 x 1053	1.67	203.59	3.14	64.84

The final decision is based on the efficiency to price per Watt ratio. Among these panels it is higher in the REC370AA model from the manufacturer REC Alpha. Its data sheet can be found in the appendix II.

4.1.2 Solar thermal panel selection

Solar thermal technology is also divided in various types of panels with different working principles. Two main groups can be identified; flat plate thermal collectors and evacuated tube collectors. The efficiency of solar thermal collectors varies alongside weather variations but, generally, it can be said that evacuated tube collectors have better overall efficiency [6]. They also have a design advantage in cold weathers as they can hardly be covered by snow. However, it can also be stated that flat plate collectors are more economically feasible because of the reduced purchase costs of the panels [7]. For this reason, FPC are considered to be the best fit for the project and this part of the study is going to focus on comparing different flat plate collector models.

In contrast with PV panel information, which is more widely distributed across the internet, information of FPC is not as accessible. In this case, only three collectors from three leading manufacturers will be compared based on their technical specifications and prices as listed on the Spanish distribution site gasfriocalor.com.

In order to be able to compare the different collectors, their efficiency needs to be calculated. The efficiency of an FPC can be calculated according to equation 4.1, as the european solar thermal industry federation indicates [8].

$$\eta = \eta_0 - a_1 \frac{T_m - T_a}{G} - a_2 \frac{(T_m - T_a)^2}{G} \tag{4.1}$$

Where:
- a_1 and a_2 are the specific heat loss coeficients of the collector.
- η_0 is the zero-loss efficiency of the collector.
- G is the solar irradiation.
- T_m is the operating temperature of the collector.
- T_a is the ambient temperature.

In this comparison, η_0, a_1 and a_2 are going to be taken from each collector's datasheet and the weather parameters will be assumed to be those of Barcelona (Spain), with an average ambient temperature of 21,2 ºC. Finally, the solar irradiance is fixed at 1000 W/m^2 and the operating temperature of the collector will be considered to be 50 ºC as advised for domestic hot water systems by the ESTIF. The result of the comparison is displayed in Table 4.2.

In the end, the selected collector is the ECOTOP VHM N from the Spanish manufacturer Ferroli. While it does not have the best efficiency under these particular assumptions, its competitive price gives it an advantage over the other two models as depicted by the efficiency to price per Wt ratio. The datasheet of the chosen thermal panel can be found in the appendix II.

Table 4.2: Comparison of three different flat plate collecotrs

Collector	Area $[m^2]$	Efficiency	€$/Wt$	Ratio
Ferroli ECOTOP VHM N	2.47	0.65	0.23	2.78
Viessman VITOSOL 100-FM	2.51	0.67	0.25	2.69
Baxi SOL250	2.37	0.69	0.29	2.41

4.1.3 Hybrid panel selection

Solar hybrid technology combines electricity and heat generation in the same component. Although hybrid panels are generally more expensive than any of the other two types, they can provide higher energy yields and make the most out of any given area.

As happened with solar thermal collectors, not much information is available online regarding this type of solar panels. In this case, the choice is not going to be based on a comparison but on proximity of the product and availability of data and pricing. Abora Solar, a spanish startup based in Zaragoza, claim to have developed the most efficient solar PVT panel in the world, the AH72-SK. This panel replaces their previous model, which they also claimed to be the most efficient panel in the past.

The technical specifications of this panel are displayed in table II.IV and its datasheet can be found in appendix II.

Table 4.3: Technical specifications of the chosen PVT panel

Panel	Abora AH72-SK
Area $[m^2]$	1.96
Nominal electric power [W]	350
Thermal efficiency	0.53
Electrical efficiency	0.18

4.2 Calculation algorithm

An algorithm is a set of rules to be followed in calculations or other problem-solving operations. In this subsection, the algorithm devised for the quoting tool will be introduced and its main characteristics will be explained.

The first step towards designing the algorithm was to define its main goals. As stated in previous sections, the aim of the project is to create a tool that will calculate the best possible domestic solar system within certain space constraints, selecting the most profitable system considering a single solar technology or a combination of solar technologies among three different ones. Therefore, the algorithm will always prioritize maximizing savings while covering the maximum possible amount of the energy demand, taking into account the space limitations of each particular study. Figure 4.3 includes a block representation of the final algorithm, which will be thoroughly explained in the following subsections.

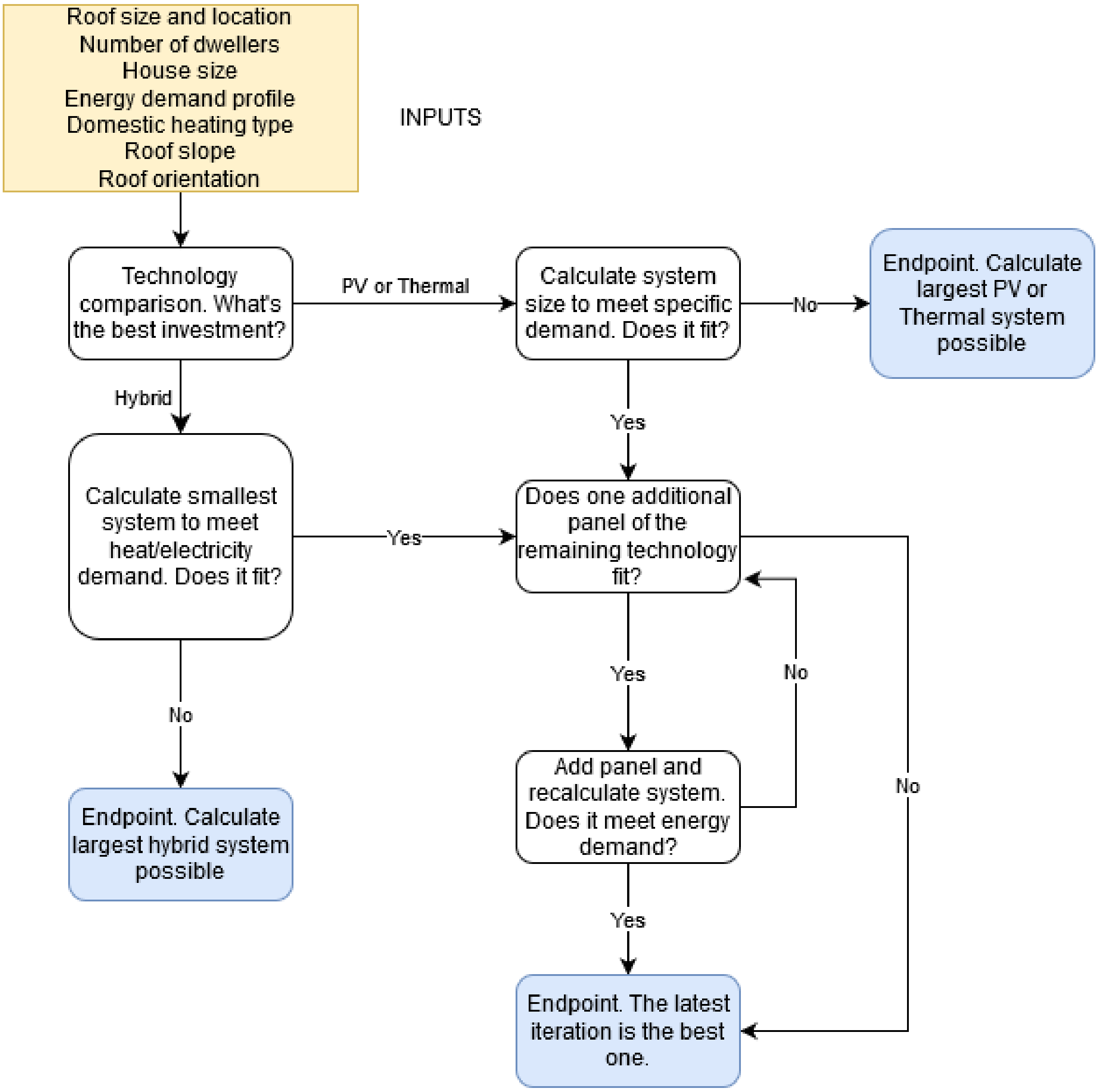


Figure 4.3: Simple block representation of the algorithm.

4.2.1 Input variables

Taking into account that the tool's purpose is to be used by the general public, it is crucial for it not to be too tedious to use. At the same time, it is also important to achieve the best possible approximations for a good customer experience all the way from the online design phase to a hypothetical system installation. For this purpose, eight critical variables have been identified that allow for the calculation to be accurate, while keeping the time investment of potential customers as short as possible. This subsection tries to introduce these five input variables and their function within the calculation process.

House location and roof size

Geographical location and roof size are probably the most important variables. Location can be used to obtain location-specific irradiation data by using an external weather database. This information is indispensable to calculate the energy yield of any solar system. On the other hand, roof size will represent the space restriction under which the calculations need to be made.

Number of dwellers N_{dw}

The user will also have to enter how many people live in the household. This variable will enable the tool to obtain a relatively good energy demand estimation without having to rely, for example, on a detailed listing of electrical components within the dwelling. Two types of energy demand will be obtained from this input variable:

- Electricity demand: traditionally, electricity demand from households can be explained as a function of habit, income, price, climate-related variables, the use of electrical appliances and other socioeconomic factors such as household size [9]. For the sake of simplicity, household size has is the chosen variable, as it allows a decent approximation without having to ask for too much data. Taking the average electricty consumption per dwelling in Spain in 2017, which was 3790 kWh, [10] and dividing it by the average number of dwellers per household in Spain (2.5), we obtain an average electricity consumption per person of 1516 kWh/year. Electricity demand will be estimated in kWh as depicted in equation 4.2.

$$D_{el} = 1516N_{dw} \tag{4.2}$$

- Domestic hot water (DHW): many scientific studies have found that there is a linear correlation between DHW demand and the number of dwellers within a household [11]. However, these studies where not conducted in Spain and consequently do not provide realistic approaches for Spanish households. Then, DHW demand is also going to be estimated based on the numbers available in the ODYSSEE [1] database. Odyssee indicates that the DHW demand in Spanish households, excluding heating purposes, averages 0.15 toe/dwelling. This translates into 697.8 kWh/year·person after the unit conversion. Equation 4.3 explains how this kind of energy demand will be computed (result in kWh).

$$D_{dhw} = 697.8N_{dw} \tag{4.3}$$

House size S_h

Just as the number of dwellers provides enough information for a comprehensive evaluation of electricity and DHW energy demand, house size is one of the main variables

[1]ODYSSEE is an energy efficiency database co-funded by the Horizon 2020 programme of the European Union

to look at when trying to estimate heating energy demand. Although weather is obviously another hugely influential variable, no scientific sources have been found that quantify the effect of weather alone on heating demand. For that reason, Spain's average numbers will be taken from the ODYSSEE database and used to calculate heating energy demand. The yearly average per square meter in Spain comes at 4.61 koe/m^2 which is equivalent to 53.61 kWh/m^2. Equation 4.4 shows how heating related energy demand will be calculated in kWh.

$$D_h = 53.61 S_h \tag{4.4}$$

Electricity demand profile

For the purpose of accurately calculating savings coming from solar PV technology, it is essential for the electricity demand profile to be estimated. That is because revenues from a PV system will enourmously depend on whether the generated electricity is used for own consumption or dumped into the grid. While feeding it into the grid will pay the owner about 3 cents/kWh, using it for their own consumption can be as much as five times as profitable under today's electricity prices.

The tool will get an idea of the electricity demand profile by asking the customer when is it that electricity is consumed in the household. As will be detailed in further sections that refer to user interface, the user will be given three options including "Morning", "Afternoon" and "Night", and will have to select one, two or all three of them. Table 4.4 shows the assumptions that will be made depending on the user's selection.

Table 4.4: Assumptions of self consumption based on user selections

Morning	**Afternoon**	**Night**	% of self consumption
×	×	✓	10
✓	×	×	30
×	✓	×	30
×	✓	✓	40
✓	×	✓	40
✓	✓	×	60
✓	✓	✓	70

Domestic space and water heating type

The most popular heating systems in Spain use natural gas, while electric ones fall in second place [12]. Due to the popularity of natural gas systems in Spain, the tool will calculate thermal panel savings based on how much they outperform natural gas. However, in order to fine-tune the algorithm and adapt to the reality that a lot of heating systems also use electricity, a question will be asked to the customers regarding the type of heating system within their households. The user will be given the option to choose between the natural gas and electric alternatives in both space heating and water heating, and estimated energy demands will vary accordingly. If there's any case where thermal energy demand is equal to zero, for example, thermal panels would no longer be considered viable for that particular case, as there would be no heating demand to be met.

Roof slope

To avoid mutual shading between solar panels, the appropriate distance between panel rows needs to be calculated. This is important because the space that we will need in a roof to place a solar panel is not equal to its size, but to the space it physically takes up plus the shading that comes with it. With this in mind, the tool will be asking for the slope of the roof in order to be able to perform the calculations shown in equation 4.5. Although the optimal value for any location in mainland Spain would be around 30 degrees, the inclination angle of the panels is fixed at 50. Choosing this more pronounced inclination will increase energy yield during the winter months while only provoking around 5% production losses (see equation 4.6).

$$d = \frac{lsin(50 - \alpha)}{tg(25 + \alpha)} + lcos(50 - \alpha) \tag{4.5}$$

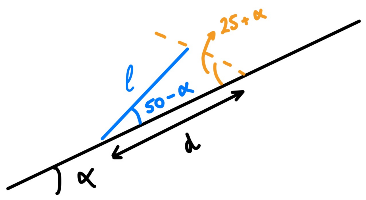


Figure 4.4: Calculation of the distance between panel rows

This distance *d* is computed according to the drawing in figure 4.4, considering that the angle of incidence of sunlight at 12:00 p.m. in the winter solstice is 25 degrees. If we multiply this distance by the width of the panels we obtain the real size they will be occupying in each particular roof.

Roof orientation

The last important variable to take into account is roof orientation. Roof orientation is extremely important because it complements the geographical coordinates in estimating the amount of solar irradiation that a particular surface is hit by. By knowing its value, the application will be able to calculate losses with respect to the optimal orientation in the northern hemisphere, which, to maximize energy output, is having the panels facing south. To make this calculation the formula shown in equation 4.6 will be used [13].

$$Losses(\%) = 100 \cdot [1.2 \cdot 10^{-4} \cdot (\beta - \beta_{opt})^2 + 3.5 \cdot 10^{-5} \cdot \alpha^2] \quad (4.6)$$

Where:
- β is the panel inclination angle (always 50º) and β_{opt} is considered to be 30º.
- α is the Azimuth angle, which is the roof orientation value provided by the user.

As an example, figure 4.5 displays the value of these losses for the 41 degree latitude and varying azimuth and inclination angles.

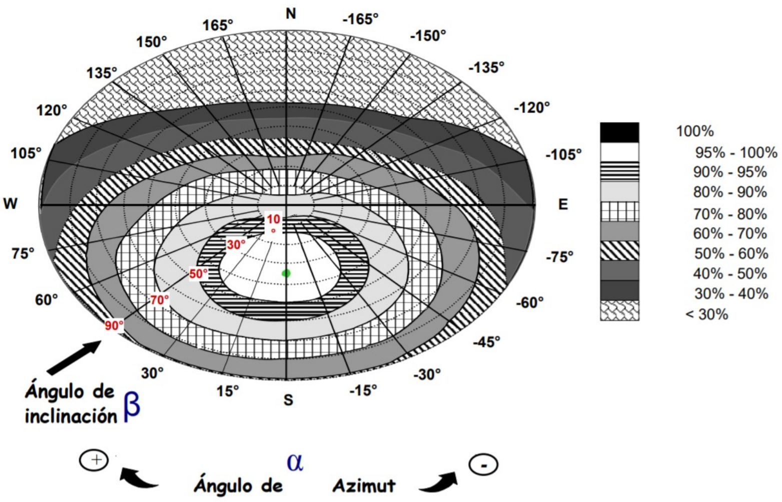


Figure 4.5: Depiction of orientation losses at a 41º latitude

4.2.2 Calculation process

As seen previously on figure 4.3, the first step of the algorithm is labeled "Technology comparison". The purpose of this step is to compare the different technologies based on profitability and help the algorithm decide on one of them to start iterating. Depending on space availability, the calculation will either run up until the end and find the optimal installation that satisfies energy demand, or stop due to space restrictions. Having made this initial analysis ensures that in limited space scenarios, were only a handful of panels fit, only the most profitable ones will be chosen.

In order to compare the different technologies, a full economic assessment will be conducted with the help of the input variables and some additional information that can be obtained from them. This analysis will be based on the cash flows per unit area of each type of panel over the total investment time, which is considered to be 25 years. By comparing the internal return rates obtained for each technology, the algorithm will be able to take a decision and choose the better performing panel in each situation. The process that needs to be executed after this initial comparison is self explanatory from what can be seen in figure 4.3, so this section is solely going to focus on explaining what this initial step consists in.

In order to make this economic analysis, both initial investment cost and cash flow for each of the analyzed periods are needed.

The formula used to calculate initial investment costs per square metre is common for all three technologies:

$$I_0 = \frac{C}{p \cdot S} \tag{4.7}$$

Where:
- C is the panel cost in €.
- p is the percentage of the total cost of installation that the panel represents.
- S is the size of a single panel in m^2.

From this point on, however, the computation of annual cash flows for each technology relies on certain particularities that make it worth separating the explanation in three different subsections.

Solar PV

For solar PV, initial investment cost is calculated according to equation 4.7, taking 1.75 m^2 as the size of the panel and 240 € as its price. Finally, it is known that, on average, PV panels represent about 58% of the total installation costs [14], so this is the value we will be giving to p.

Cash flow is calculated by substracting operation and maintenance cost from income. In this study, because they represent very low fees, no O&M costs have been considered. Therefore, only income coming from the generation of electricity will be taken into account in the Cash Flow calculation.

For PV, two main income surces have been identified. In the first place, every kWh generated by the system and directly consumed within the household will be replacing a kWh that would otherwise be coming from the grid. As a consequence, this kind of consumption will imply savings per kWh equal to the electricity price. Secondly, every KWh that is generated and not used is going to be directly sold and fed into the grid in exchange for a small compensation. This compensation is around 3-5 cents per kWh as of 2020.

Calculating the income coming from a PV system means multiplying the total amount of electricity generated by the savings/compensation you get from it. Equation 4.8 explains how the cash flow per metre calculation is done for each year i.

$$CF_i = E \cdot P_{e,i} \cdot SC + EP_{s,i} \cdot (1 - SC) \tag{4.8}$$

Where:
- E is electricity generated in kWh during the year i per square metre.
- P_e is the average electricity price in the year i in €/kWh.
- SC is the percentage of self consumption of the generated electricity.
- $P_{s,i}$ is the price of the electricity surpluses for year i in €/kWh.

An explanation is needed as to how the values of the variables in equation 4.8 are reached. The next paragraphs depict how electricity generation, prices and self consumption are calculated.

Equation 4.9 shows how the amount of generated electricity per square metre is computed.

$$E = \frac{P_n}{S} \cdot PSH \cdot 365 \tag{4.9}$$

Where:
- PSH are the daily average peak sun hours in the studied location.
- P_n is the nominal rated power of the selected PV panel in kW.
- S is the surface of the selected PV panel in m^2.

By using the roof location, which is one of the input variables, a weather database can be accessed and the value of PSH for that particular location extracted. Peak sun hours are a measure of how many solar radiation is received in a day; they tell how many hours it would take to get the same amount of radiation under standard test conditions(W/m^2). This value can be multiplied by the nominal rated power of the PV panel to obtain energy yields because this power value is the one obtained under STC. Finally, the daily electricity production is multiplied by 365 days in a year and divided by the surface of a panel to obtain a yearly electricity yield in kWh/m^2.

Other important factors in the cash flow calculation are electricity prices and surplus compensations. These represent a challenge in the process of correctly estimating revenue, as it is very difficult to foresee electricity prices in the long term. However, looking at past trends, a steady increase in household electricity prices has been taking place since 2008 [15]. Figure 4.6 shows this evolution.

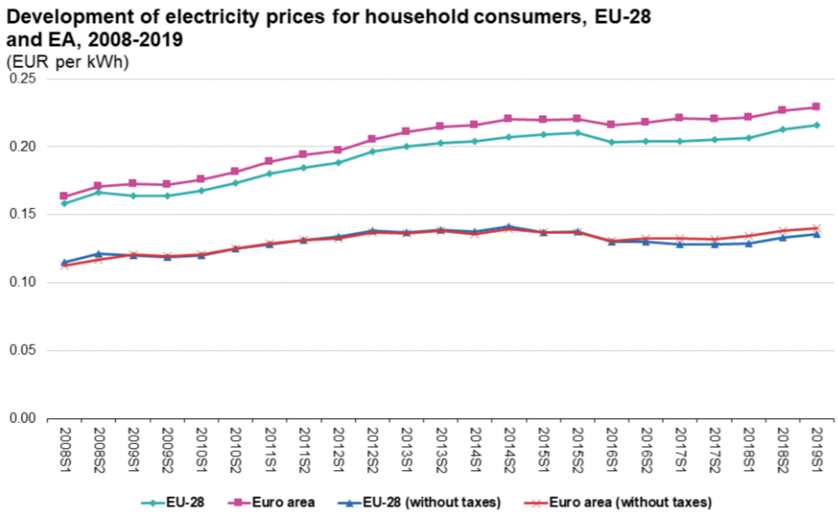


Figure 4.6: Evolution of household electricity prices in Europe

The graph shows an average growth rate of electricity prices of about 3% yearly. Considering that this trend will continue into the future, electricity prices used to calculate revenue for each period will be obtained from equation 4.10, which estimates them based on the expected evolution of the consumer price index.

$$P_{e,i} = P_{e,0} \cdot (1 + CPI)^i \tag{4.10}$$

Where:
- $P_{e,0}$ is the average electricity price during year 0 in €/kWh.
- CPI is the expected average evolution of the consumer price index during the 25 years after the investment.

A realistic assumption regarding these two variables would be to take an initial electricity price of 0,15 €/kWh and an average expected CPI rise of 2% yearly. In the same way, surplus compensations are calculated as depicted below in equation 4.11, taking 3 cents/kWh as the initial compensation for surplus electricity.

$$P_{s,i} = P_{s,0} \cdot (1 + CPI)^i \tag{4.11}$$

Where:
- $P_{s,0}$ is the average electricity surplus compensation during year 0 in €/kWh.
- CPI is the expected average evolution of the consumer price index during the 25 years after the investment.

Lastly, the percentage of self consumption is taken from the assumptions that have already been explained previously in table 4.4.

Everything that goes into equation 4.8 has been explained. The final metric of the comparison is the internal rate of return, which can be calculated in different ways. The first one is Schneider's approximation, shown in equation 4.12, which allows the calculation of IRR with a single formula without having to iterate. However, the result can be far from reality.

$$r = \frac{-I_0 + \sum_{i=1}^{25} CF_i}{\sum_{i=1}^{25} i \cdot CF_i} \tag{4.12}$$

The second one consists in iterating the net present value formula until a discount rate that makes it equal to zero is discovered. This is the one that better adjusts to the IRR definition and the one that has been chosen for this project. Equation 4.13 shows how the NPV is to be calculated.

$$NPV = \sum_{i=1}^{25} \frac{CF_i}{(1+r)^i} - I_0 \tag{4.13}$$

Where (in both 4.12 and 4.13):
- I_0 represents initial investment cost in €.
- r is the internal rate of return.
- CF_i is the cash flow result after the period i in €.

After this last iterating step, a value of IRR is obtained that allows for the comparison to take place.

Solar thermal

Although the economic analysis for the solar thermal technology looks a lot like the one that has just been introduced for solar PV, some things do change from one to the other and need to be explained.

The initial investment cost formula remains the same (equation 4.7), but the percentage of the installation that the panels represent changes from 58 to 38 per cent, as thermal systems contain many more and pricier components such as tanks, insulation, etc. [16].

The cash flow formula does vary slightly. Apart from taking into account that every generated kWh is now replacing natural gas instead of electricity, demand variations also need to be considered. Whereas electricity demand will remain almost static throughout the year, thermal energy demand varies greatly with the need of household heating in winter. Consequently, when trying to satisfy energy demand in the coldest season, it must be taken into account that thermal panels will not be as profitable during the summer months; they will be sitting in the roof receiving unusable sunlight. Therefore, although this was not required for PV systems, the total size of the thermal panel array must be known in order to calculate profitability per square metre.

As seen on equation 4.14, the total amount of the generated thermal energy is multiplied by natural gas prices and divided by the total sistem size in order to get the real cash flow figure in € per m^2.

$$CF_i = \frac{(T_w + T_s) \cdot P_{g,i}}{N_{panels} \cdot S} \tag{4.14}$$

Where:
- T_w is the thermal energy demand in winter in kWh.
- T_s is the thermal energy demand in summer per kWh.
- P_s is the expected natural gas price in Spain during the period i.
- N_{panels} is the number of panels.
- S is the size of a the chosen thermal panel.

Similarly to what happened with some variables in equation 4.8, some context is needed for the variables in equation 4.14.

In the first place, thermal energy demands are estimated as depicted in section 4.2.1. The total thermal energy demand comes from adding up DHW demand and household heating demand, if applicable.

The aforementioned need to size thermal systems in order to calculate profitability is reflected in the N_{panels} variable in equation 4.14. This variable has a linear correlation with the average winter energy demand, which has been chosen as the adequate amount of thermal energy the system should be able to provide. The number of panels needed for the thermal installation is computed as equation 4.15 shows.

$$N_{panels} = \frac{T_w}{151 \cdot PSH \cdot \eta_t \cdot S} \tag{4.15}$$

Where:
- T_w is the thermal energy demand in winter in kWh.
- 151 are the total number of days in the winter season.
- PSH are the peak sun hours in a certain location.
- η_t is the thermal efficiency of the chosen panel.
- S is the size of the chosen panel in square metres.

The last variable of equation 4.14 that needs to be put into context is natural gas price. As with electricity, it will be assumed that gas prices will vary according to a CPI yearly increase of 2% as explained in equation 4.10. In the case of natural gas, Spain has two regulated tariffs depending on the level of consumption of the user. If the user needs less than 5000 kWh yearly, the first tariff will apply and the initial price for the calculation will be equal to 6 cents/kWh. On the other hand, if the user needs more than 5000 kWh yearly, the second tariff comes into play at a rate of 5,2 cents/kWh. Both natural gas prices correspond to the regulated tariffs as of March 2020.

Finally, the internal rate of return is calculated as explained in the PV subsection and compared to that of the other two technologies.

Hybrid PVT

Having explained how the analysis is conducted in both photovoltaic and thermal technologies, the hybrid version is easy to describe as it simply is a joint evaluation of both electricity and thermal energy yields. The initial investment cost formula (Equation 4.7) is still valid. Again, the percentage of installation cost that the panels represent needs to be changed, now to a 56,76% of the total investment costs [14].

The cash flow formula is obtained from adding up both previous formulas, as a hybrid panel is essentially a combination of a photovoltaic and a thermal panel. Equation 4.16 shows what the cash flow formula looks like.

$$CF(i) = E \cdot P_{e,i} \cdot SC + EP_{s,i} \cdot (1 - SC) + \frac{(T_w + T_s) \cdot P_{g,i}}{N_{panels} \cdot S} \tag{4.16}$$

The variables that appear in equation 4.16 represent the same as in the previous cash flow equations (4.8, 4.14) and assumptions for self consumption, thermal energy demand and electricity and natural gas prices remain the same.

Finally, the internal rate of return can be calculated in the same way as before and compared to the other two technologies.

4.2.3 Relevant assumptions

To finish the explanation of how the tool at hand will handle the calculation process, it is necessary to present the values of certain assumptions that have been made concerning different constants. These assumptions are:

- Initial electricity price: 0.15 €/kWh
- Initial surplus compensation amount: 0.03 €/KWh
- Initial natural gas price (1st regulated tariff): 0.061 €/KWh
- Initial natural gas price (2nd regulated tariff): 0.054 €/KWh
- PV panel price: 240.0 €
- Thermal panel price: 377.2 €
- Hybrid panel price: 397.6 €
- Interest rate: 2%
- Expected annual CPI increases: 2%
- Investment horizon: 25 years

Chapter 5

Technical implementation

The second objective of this project was to get to a working prototype. This has been made possible through the creation of a web application with the use of the JavaScript, HTML and CSS programming languages. While HTML and CSS have been used for the design of the website itself, JavaScript can be considered to be the important part of the coding process because it is in charge of the calculations and the external queries that need to be conducted.

Figure 5.1: Javascript logo

Overall, the devised web application is what is known as a single-page application (SPA). SPAs are generally charachterized by having thin server architectures because they move the logic from the server to the client side. The SPA approach has been chosen because, as the single-page applicaton name indicates, there is only one page to be loaded. As a consequence, although the initial load time is greater than in server-based applications, this helps reduce loading times within the app to almost zero, greatly improving the user experience. What the present tool does, in summary, is pre-load the necessary scripts before the website is loaded and then dynamically change its contents according to the interaction it has with the user.

5.1 Plugins and APIs

An important part of the app are the plugins that have been used to introduce some important functionalities to the website and the APIs (Application Programming Interfaces) that allow the tool to query external databases and obtain information from them. All of them will be introduced in this subsection, and the practical implementation will be shown for the most important ones. A general overview of the application architecure is shown in figure 5.2.

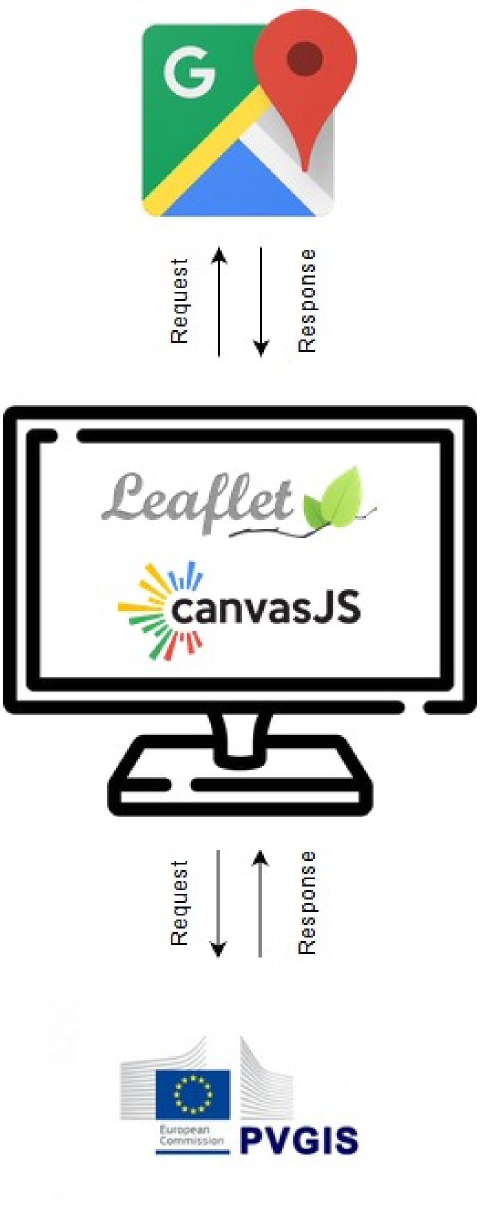


Figure 5.2: Basic application architecture overview

5.1.1 Leaflet

Leaflet is an open-source JavaScript library that allows for the inclusion of interactive maps to this project. It comes with a very wide range of mapping features and relies on the support of multiple third-party plugins developed by its community.

Figure 5.3: Leaflet logo

Together with Leaflet, three of these third party plugins have been used.

1. The leaflet-geoman plugin has been used to introduce the necessary drawing functionalities to the map. Leaflet does include drawing tool support but geoman makes it easier to extract location data out of the drawn layers, which is essential for the purpose of this project.

2. The leaflet-control-geocoder plugin has been used to introduce a search bar functionality to the map.

3. The leaflet-google-mutant plugin has been used to correctly integrate Leaflet with the Google Maps API, which is harder to do without using it.

Leaflet implementation

The following listing shows the code that has been used to implement the interactive satellite map into the tool. This includes the map initialization, the use of Google Mutant to allow Leaflet and Google Maps integration and the inclusion of the geoman map controls and the geocoder search bar.

```
let myMap = L.map('myMap', {zoomControl: false }).setView([41.3851,
    2.1734], 13);

var satImg = L.gridLayer.googleMutant({ type: 'satellite' }).addTo(myMap
    );

myMap.pm.addControls({
    position: 'topleft',
    drawCircle: false,
    drawRectangle: false,
    drawPolyline: false,
    drawMarker: false,
    drawCircleMarker: false,
    editMode: false,
    cutPolygon: false,
});

L.control.scale().addTo(myMap);

L.Control.geocoder({
    collapsed: true,
    expand: "click",
    position: "topleft"

}).addTo(myMap);
```

Listing 5.1: Leaflet implementation

5.1.2 CanvasJS

CanvasJS is a plugin that allows for the inclusion of interactive charts within websites or apps. The trial version of CanvasJS has been used to display the yearly expected system cashflows in the final dashboard of the tool by means of a bar chart.

Figure 5.4: CanvasJS logo

The code used for the implementation of the canvaJS utility is shown in appendix I.

5.1.3 PVGIS

The Photovoltaic Geographical Information System (PVGIS) is part of the joint research center of the European Comission and provides all kinds of useful information for PV systems. Among other things, PVGIS maintains a free access database that anyone can consult. Within this project, the PVGIS API has been used to obtain location-specific irradiation data, which is essential to calculate the energy yield of prospective solar systems.

Figure 5.5: PVGIS logo

PVGIS API call

The PVGis API call is made through an XML HTTP request automatically whenever a polygon is drawn on the map. The app extracts the geographical location of the first drawn point from the Leaflet layer via the Turf JavaScript library and translates it into GeoJSON format. The latitude and longitude are then put into strings that can be placed inside the PVGIS request.

```
myMap.on('pm:create', e => {
    const layer = e.layer;
    roofSize = (turf.area(layer.toGeoJSON())).toFixed(2);
    console.log(layer.toGeoJSON());
```

```
    coord1 = layer.toGeoJSON().geometry.coordinates[0][0][0];
    coord2 = layer.toGeoJSON().geometry.coordinates[0][0][1];

    var xhttp = new XMLHttpRequest();
    xhttp.onreadystatechange = function() {
    if (this.readyState == 4 && this.status == 200) {
        ESHString = xhttp.responseText;

        }
    };

    var lat = coord2.toString();
    var lon = coord1.toString();

    xhttp.open("GET", "https://re.jrc.ec.europa.eu/api/mrcalc?lat=" +
       lat + "&lon=" + lon + "&startyear=2016&selectrad=1&angle=50",
       true);
    xhttp.send();
});
```

Listing 5.2: PVGIS API call

5.1.4 Google Maps API

Lastly, the Google Maps API has been used to obtain the satellite imagery that needs to be displayed on the interactive map. Google Cloud services are not free but the company grants 300 USD of initial trial credit, which is more than enough for the development of this project. Just to give an example, during the coding process, 582 API calls were made that amounted to a total cost of 3,65 USD.

Figure 5.6: Google maps logo

The Google Maps API is called via a script tag in the HTML section of the code, where a special API key needs to be specified, and the maps are implemented together with Leaflet as shown in listing 1.

5.2 Implementation of the algorithm

Overall, the code of the application is quite simple. It contains a lot of trivial variable declarations and simple mathematical operations which, although important for the correct functioning of the tool, are not worth mentioning in this report. Therefore, this section is going to focus solely on the most important aspect of the calculation process, which is how the algorithm has been implemented. The rest of the code can be found uncut in appendix I.

5.2.1 Code

After having obtained the necessary input variables (the process will be shown in chapter 6) the code follows the same structure that was detailed in section 4.2 to get to an IRR value for each of the three technologies and be able to compare them.

The following listing shows how IRR for PV panels is calculated.

```
//Calculation of generated electricity for PV

var generatedElectricity = orientationFactor * 0.001 * ESH * 365 *
    panelPower/panelSize;

//Calculation of the Cash Flow array for PV

var yearlyValue = cashFlowPV(generatedElectricity, futurePrice, sC,
    futureSurplusPrice, interestRate, investmentTime, initialInvestment);

var vanPV = (yearlyValue.reduce((a,b) => a + b, 0)).toFixed(2);

//Calculation of the internal rate of return with a 0.01 error margin.

var interestIRR = 0;

while (cashFlowPV(generatedElectricity, futurePrice, sC,
    futureSurplusPrice, interestIRR, investmentTime, initialInvestment).
    reduce((a,b) => a + b, 0) > 0){
  interestIRR += 0.0001;
}

var IRR = (interestIRR * 100).toFixed(2);
```

Listing 5.3: Calculation of IRR for PV

The "cashFlowPV" function does what equation 4.8 describes. It iterates over the investment period and outputs an array containing the corresponding cash flows. The final *while* loop is used to discover the IRR; it starts from 0% and keeps adding up until the NPV of the investment is below 0.

For the other two technologies the process is quite similar. For thermal, we first determine which of the two regulated tariffs applies based on the total thermal energy demand obtained from each user (see how in section 4.2.1). We then proceed to use the "cashFlowT" function and compute the IRR in the same way we did before. Finally, the "cashFlowH" function is executed to obtain the annual cash flows for PVT and allows us to find the IRR for this particular technology. In both cases, the code is similar to what can be observed in listing 5.3 and it can be found in the appendix I.

Once the three IRRs have been found, we can compare them to each other and advance to the next steps of the algorithm depending on the comparison result. The practical implementation of these last steps is not complex, it just consists of a series of conditional statements that do exactly what figure 4.3 details. Once again, the code can be found in appendix I.

Chapter 6

User interface

The user interface (UI) is an essential part of the tool, as it interacts with the users in order for the application to obtain the necessary information. Having the users in mind, the UI needs to make sure they have a positive user experience while also ensuring the reliability of the information they share. In general, this is achieved by having short loading times and keeping the whole process short, asking very few brief and concise questions. In this chapter, the design of the application is discussed and the user flow is presented.

6.1 Context: the Megawatt brand

To have a tool open up directly in the browser without any kind of context or information to back it up could be a bit strange. That is why prior to the making of the design of the tool, a brand was created under the name of Megawatt.

Figure 6.1: Logo of Megawatt

To follow some minimal design guidelines, it was decided for the color palette of the tool to revolve around the two colors that appear on the logo. These two are (in HEX code) #ffd600 (yellow) and #062247 (blue). Making use of this brand imagery, a homepage was designed to serve as an introductory page that users will need to go through before accessing the tool. Figure 6.2 shows what this homepage looks like.

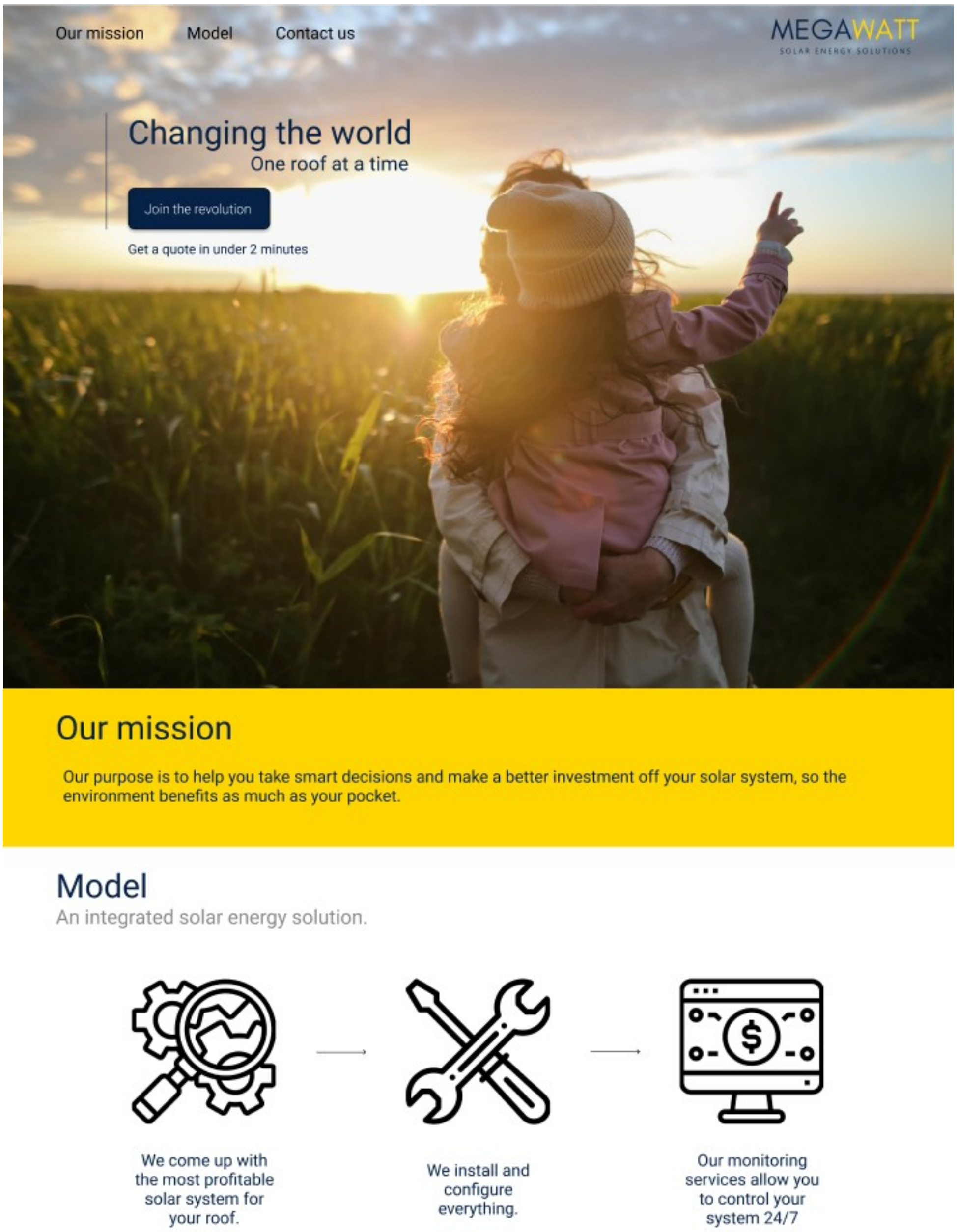


Figure 6.2: Megawatt website homepage

6.2 Obtention of the input variables

The input variables presented in section 4.2 form the base of everything that comes afterwards. Therefore, it is important to introduce how they are obtained and what is the interaction that the user has with the website in the process.

After clicking the "Join the revolution" button in the homepage, users will be guided to the first step, where they will be asked to draw their roof on a map, as shown in figure 6.3.

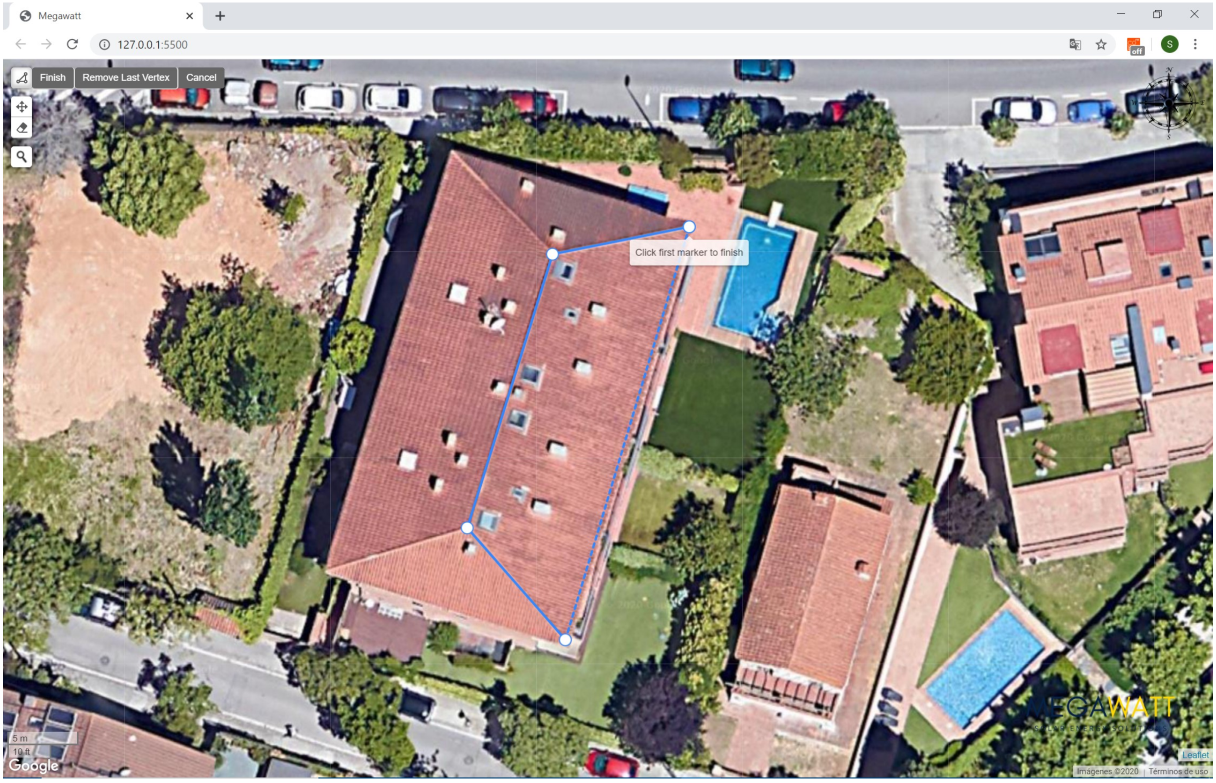


Figure 6.3: Example of the drawing process

From this drawing two things are obtained: the area of the roof and its coordinates. As mentioned in section 4.2.1, the roof size represents the space restriction that we will need to take into account and the coordinates will be used to obtain the solar irradiation of each particular location.

Right after finishing the roof drawing, the next step appears automatically on screen. This second step is the final one and requires six short questions to be answered. They can be grouped into three different groups of two questions each, based on how the user is going to answer them. Figure 6.4 shows the first two questions.

Figure 6.4: Questions 1 and 2

These first two questions are used to estimate the total energy demand of the household and are answered intuitively by clicking on the "-" and "+" buttons. This input style ensures the validity of the obtained data for the subsequent steps, as nothing apart from integer numbers can be input. The second group of questions is answered by means of checkboxes.

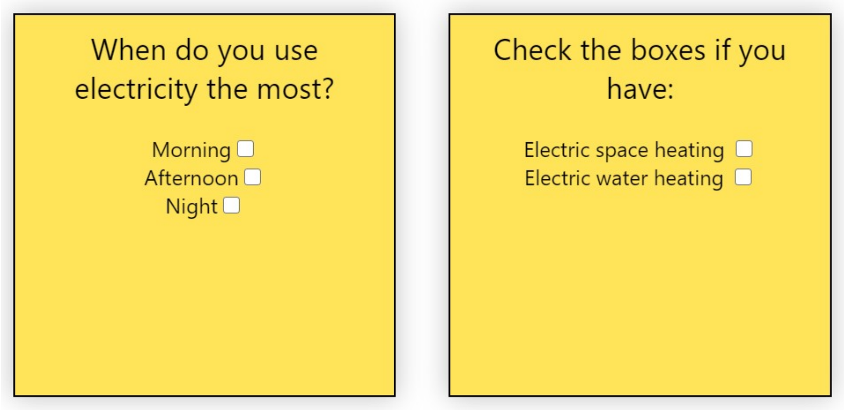


Figure 6.5: Questions 3 and 4

These questions serve the purpose of getting to know our users better, as explained previously in section 4.2.1. Firstly, by knowing the periods of major electricity consumption we will be able to better estimate the profitability of PV and hybrid panels. Secondly, knowing whether a house uses electrified water or space heating will be useful to correctly allocate the previously calculated energy demands, which in turn also means being better at estimating the profitability of the systems we are trying to plan out.

The last group of questions, as can be observed in figure 6.6, is answered with the help of slider bars.

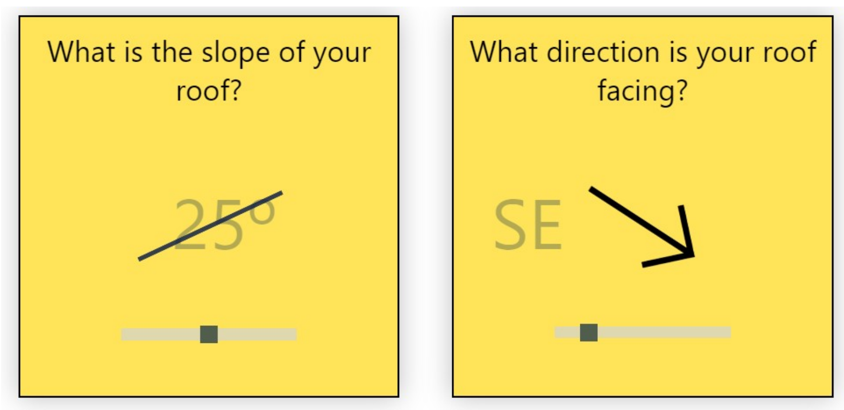


Figure 6.6: Questions 5 and 6

By knowing the answers to these questions, we are able to calculate the energy yield of our system more accurately.

6.3 Presentation of the results

After having answered these questions, the system can be calculated and the user is taken to the final dashboard, which can be seen in figure 6.7.

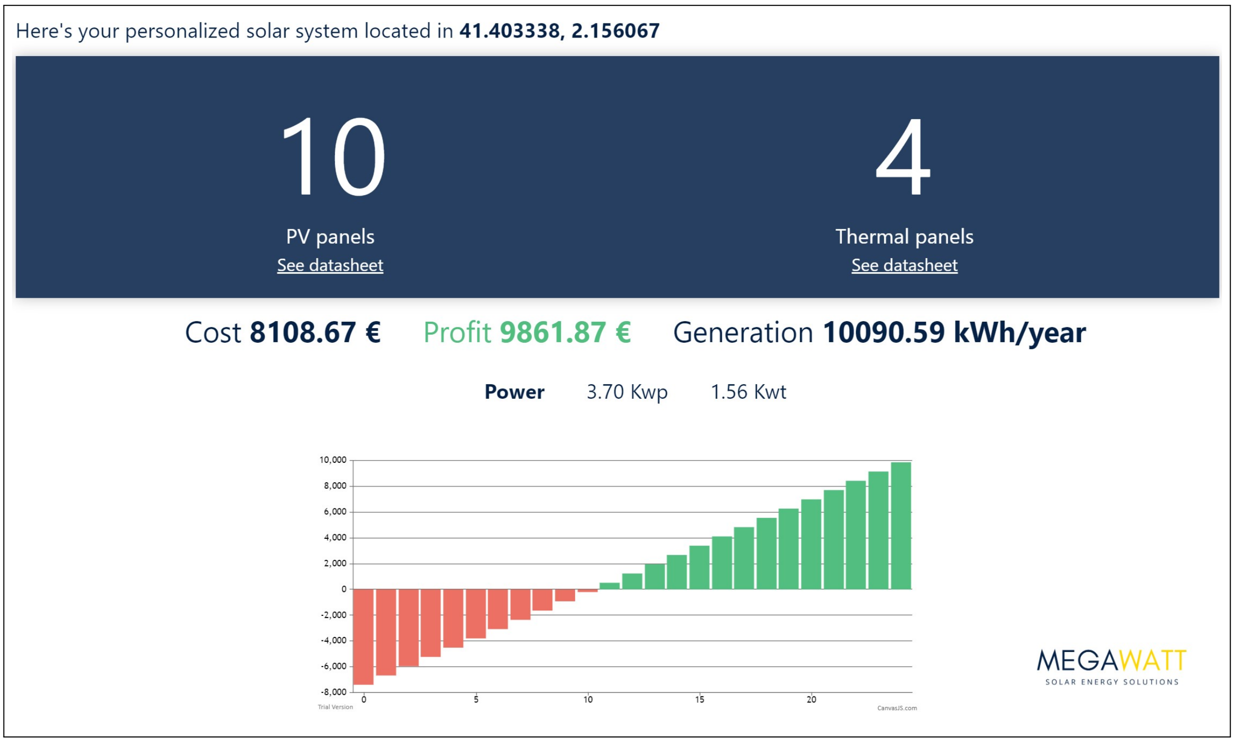


Figure 6.7: Output dashboard

The dashboard includes the most important details of the calculated system such as the number of panels to be installed (with a link to their technical datasheet), the total cost of the system, the profit to be made over the investment period, the total annual energy generation and the electric and thermal power to be installed. It also includes a bar plot, implemented with CanvasJS, that shows how profits evolve over time and allows, by hovering on it, to know exactly what the accumulated cashflow is at a certain period within the investment horizon.

Chapter 7

Usage example and result assessment

After having explained how the tool has been developed and what the user interface is like, it is now time to go through a system configuration process and evaluate the obtained results. Afterwards, the final results will be compared to those that some of the tools that were analyzed in chapter 3 output under similar search parameters.

7.1 Example

As explained in the previous chapter and just as any other customer would do, we first draw a roof on the map as shown in figure 7.1.

Figure 7.1: Map drawing example

Following this first step, we answer the questions in the second step as shown in figure 7.2.

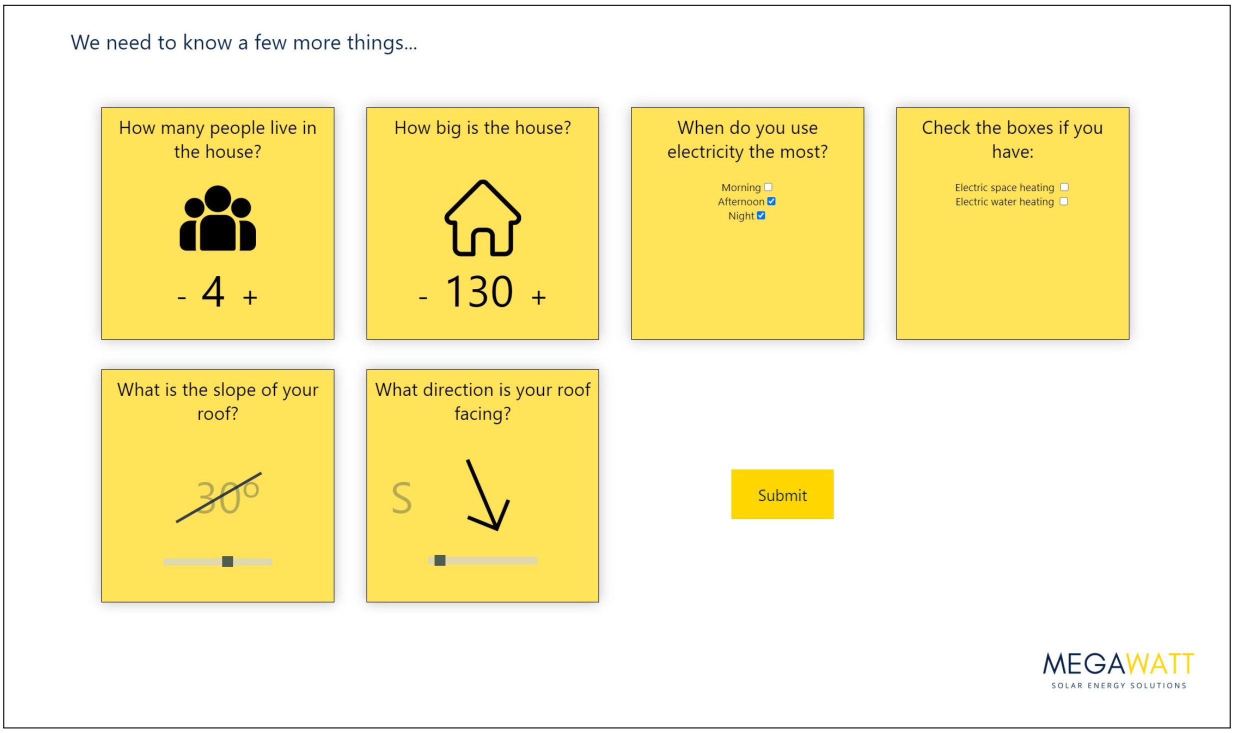


Figure 7.2: Step 2 example

With these inputs the outcome turns out to be a solar system containing 1 thermal panel and 9 hybrid PVT panels with the following key metrics:

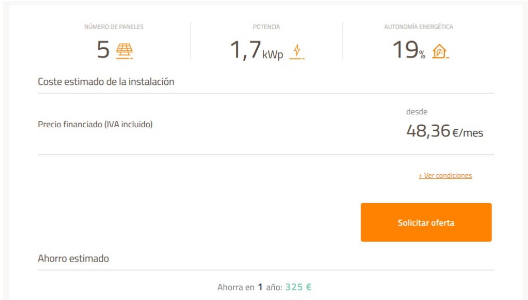
Cost	7297.12 €
Profit	16703.74 €
Total generation	15120.26 kWh/year
Electric power	3.15 kWp
Thermal power	11.19 kWt

It's worth pointing out that the "Total generation" figure includes both electricity and thermal energy. Of course, it excludes all of the thermal energy that is generated throughout the year and is not able to be used due to a lack of demand. The annual savings, which can be obtained from dividing the total profit by the total investment time, amount to 668 € per year.

7.2 Result assessment

Under similar inputs, the offers of Repsol Solify and EDP Solar have been the ones depicted in figure 7.3.

(a) EDP solar offer



(b) Solify offer

Figure 7.3: EDP Solar and Repsol Solify outputs

EDP Solar, as we had seen before, has two outputs; one is a low investment opportunity and the other, which appears in figure 7.3a, is the optimal solution that maximizes profit. In this case, EDP says that with an initial investment of 7499 €, 9 panels will be installed with a total peak power of 4 kWp and annual savings will amount to 572 €.

Repsol Solify's offer is lower. The total investment cost is undisclosed, but they do provide the total number of panels, which is 5, together with the annual savings. With this 1.7 kWp system they say these savings amount to 325 €.

A positive realization to be made when comparing these two offers with the one obtained from the developed tool is that their magnitudes are similar. What maybe stands out is that the hybrid system Megawatt is offering turns out to be cheaper than the PV system of similar order offered by EDP. This is strange because hybrid solar energy should be more expensive than solar PV. Nevertheless, this can be explained by profit margins not being included in the Megawatt offer.

It is certainly difficult to say whether the estimations are valid, and much more so when taking into account that we are comparing an almost entirely hybrid system to two completely photovoltaic based ones. So, although it is hard to reach conclusions without any practical experience, it can be said that the numbers do not look far-fetched at all.

Chapter 8

Budget

The total cost of the project can be divided into human capital costs and the costs associated with IT resources. The breakdown of each one of these costs is as follows:

Table 8.1: Breakdown of human capital costs

Task	**Time spent [h]**	**Hourly cost [€/h]**	**Total cost [€]**
Planning	10	15	150
Research and ideation	60	30	1800
Web design	10	30	300
Web development/testing	100	30	3000
Reporting	40	15	600
		TOTAL	**5850 €**

Table 8.2: Breakdown of IT related costs

Description	**Cost [€]**	**Amortization period**	**Usage period**	**Total cost [€]**
Laptop	1350	8 years	5 months	70
Online JS development course	16	-	-	16
Google Cloud Services	3	-	-	3
Programming software	Free	-	-	Free
Overleaf - LaTeX editor	Free	-	-	Free
			TOTAL	**89 €**

The total cost of the project turns out to be **5939 €**.

Chapter 9

Environmental impact

It can be said that the process of making this project has had no considerable impact on the environment aside from the small amount of energy that the necessary laptop has operated on. However, because this project revolves around the idea of solar energy and its expansion, it seems reasonable to provide a short analysis of as to why society should be moving in this direction.

9.1 A short discussion on the energy transition

In the last centuries, humanity has been able to find solutions to a great deal of problems that have largely improved the quality of life of billions. This was powered by copious amounts of cheap and high quality energy coming from fossil fuels, which still are our main source of energy today. However, the paradigm needs to change, as energy coming from fossil fuels becomes increasingly harder to extract from the ground and their externalities make it impossible to carry on with their consumption at the actual rates.

Such a trend can be observed with the energy return on investment (EROI), which is the ratio of the quantity of energy obtained from a given process to the quantity of energy that was consumed in that same process . This metric is nearly impossible to calculate accurately because of the enormous amount of variables that go into it, but while many scientific studies differ on what the exact EROI values of different technologies are, many other studies reach similar conclusions when it comes to their past and future evolution.

It is relevant to mention that a wide range of economic theories orbit around the idea of EROI and use it to explain possible recessions, upswings in the economy or changes in the electricity prices. Notwithstanding how fascinating these theories are, they will not be explored in the present document as it would take another whole thesis to comment on them and the need for an energy transition can be explained regardless.

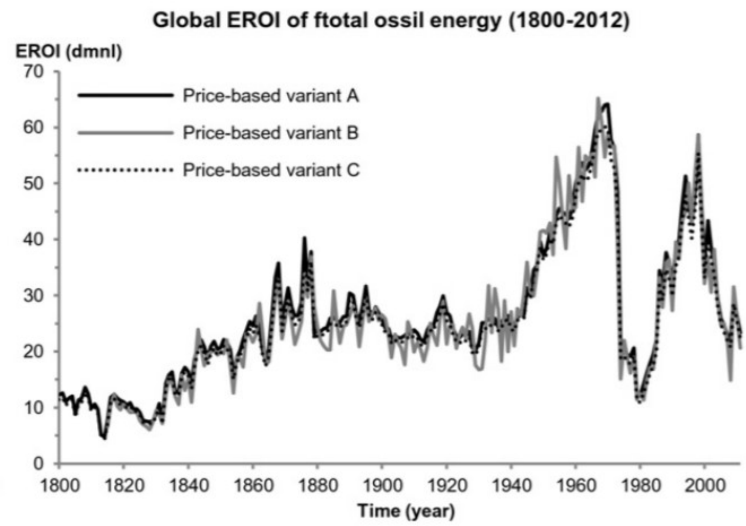


Figure 9.1: Evolution of the joint EROI of fossil fuels

As can be seen in figure 9.1, the current global average EROI for fossil fuels is close to 20:1 and, according to this same study, is expected to keep descending in the coming years as fossil fuel production resorts to more and more marginal resources [17]. In contrast, the EROI of solar PV currently ranges from 5 to 30:1 [18] and is only expected to rise from here, as technology improvements happen and economies of scale keep making the production process of modules more material and energy efficient.

Overall, solar and other renewable energies lack some of the desireable traits of fossil fuels: they are not as energy-dense, have lower EROIs as of today and tend to be intermittent. However, the costs of some of those renewable energies are already comparable to those of fossil fuels and are expected to keep falling.

Fossil fuels have solved a lot of problems and have brought humanity to a whole different stage, and it may be scary to think about not being able to rely on such stable and convenient sources of energy. But the truth is, be it for their externalities or their scarcity, that it is obvious that their era is coming to an end. Therefore, the question to pose is not whether an energy transition is needed, but when do we want it to happen.

It is unknown if a revolutionary new technology will appear in the near future, but even if project ITER turns out to be a success and nuclear fusion becomes a reality, it will take years to test and install commercial reactors and, by that time, the 1.5 ºC mark set by the Paris agreement will not be attainable if we did not start making efforts today. So the answer to when the energy transition needs to take place is as soon as possible; because the necessary technologies are already available and the EROI of fossil fuels, whose expenditure is undeniably necessary to bring this transition to life, is at the highest that it will ever be from now on.

Chapter 10

Conclusions

Looking back on the beginning of this project there were two main objectives; to devise a calculation process for a solar quoting tool and to create a working prototype based on it. As is proven by the present document, both objectives have been achieved and, apart from these more formal aspects, the project has also successfully served the purpose of providing invaluable experience in the areas of product design, solar energy and web development.

In order to get to the final result, it was first necessary to conduct an initial market study with the aim of comprehending the actual state of the art of solar quoting tools. Afterwards, some time was spent in trying to find an algorithm that fitted the requisites of the project, which took some iterations from the first raw idea to the final outcome. Finally, the tool was implemented as a web application with the help of the Javascript programming language.

In respect to the results obtained by the tool, a much more in depth analysis would be needed in order to determine whether its estimations are realistic or not. A practical case was briefly analyzed in chapter 7, where it was observed that the final estimations for that particular scenario didn't look like they were too far away from reality.

The project had defined but flexible goals, which has intrinsically translated to a great deal of freedom in terms of decision making. Especially during the ideation process, many features had to be left out due to the relatively short time span of the project. Some of these features and other improvements can be found in section 10.1.

10.1 Future improvements

1. **Save and resume projects**: The inclusion of login capabilities into the website with the aim of being able to save projects and resume them afterwards.

2. **Improved dashboard**: The developed dashboard has a poor design and contains very little information due to the lack of time available during the development process. Moreover, the current dashboard does not make use of a lot of data which is already stored in the form of variables within the code. By using it and display-

ing it elegantly, the user experience could be improved.

3. **Dynamic assumptions**: As mentioned in section 4.1, a lot of assumptions are made that make the tool capable of doing making estimations within mainland Spain and regions of similar latitude, but that make it completely useless if we want to use it in the southern hemisphere, for example. Some additions could be made to the code in order to support other regions adequately by dynamically changing the considered assumptions based on location.

4. **Shading**: In this project, the problem of mutual shading between panels was adressed. However, ordinary shading coming from nearby trees or buildings is also important and was not taken into account. Maybe with future tools it will even be possible to implement this capability simply from satellite imagery.

Acknowledgements

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Finally, I want to give a huge shoutout to all of my friends for always being there and especially to "@etseibers", for the endless day-long study sessions that would have appeared to be dull and meaningless without them.

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Appendices

I Code

HTML code

```html
<!DOCTYPE html>
<html>
<head>
    <meta charset='utf-8'>
    <meta http-equiv='X-UA-Compatible' content='IE=edge'>
    <title>Megawatt</title>
    <meta name='viewport' content='width=device-width, initial-scale=1'>
    <link rel='stylesheet' type='text/css' media='screen' href='css/style.css'>
    <link rel="stylesheet" href="https://unpkg.com/leaflet@1.6.0/dist/leaflet.css"
    integrity="sha512-xwE/Az9zrjBIphAcBb3F6JVqxf46+CDLwfLMHloNu6KEQCAWi6HcDUbeOfBIptF7tcCzusKFjFw2yuvEpDL9wQ=="
    crossorigin=""/>
    <link rel="stylesheet" href="css/leaflet-geoman.css">
    <link rel="stylesheet" href="libs/leaflet-search.min.css">
    <link rel="stylesheet" href="https://unpkg.com/leaflet-control-geocoder/dist/Control.Geocoder.css" />
    <script src="https://unpkg.com/leaflet@1.6.0/dist/leaflet.js"
    integrity="sha512-gZwIG9x3wUXg2hdXF6+rVkLF/0Vi9U8D2Ntg4Ga5I5BZpVkVxlJWbSQtXPSiUTtC0TjtGOmxa1AJPuV0CPthew=="
    crossorigin=""></script>
    <script src="js/mapa.js" defer></script>
    <script src="js/leaflet-geoman.min.js"></script>
    <script src="libs/leaflet-search.min.js"></script>
    <script src='js/funcions.js' defer></script>
    <script src='https://unpkg.com/@turf/turf/turf.min.js'></script>
    <script src="https://maps.googleapis.com/maps/api/js?key=INSERT API KEY HERE" async defer></script>
    <script src='https://unpkg.com/leaflet.gridlayer.googlemutant@latest/Leaflet.GoogleMutant.js'></script>
    <script src="https://unpkg.com/leaflet-control-geocoder/dist/Control.Geocoder.js"></script>
    <script src="https://canvasjs.com/assets/script/canvasjs.min.js"></script>
</head>

<body>
    <div id = "myMap"></div>
    <div id = "logoDiv"><img id = "logo" src="images/logo.png"></div>
    <div id = "preguntes"><p style="font-size: xx-large; color: #062247">We need to know a few more things...</p>
        <div class = "pregunta">
            <div class="textPregunta">How many people live in the house?</div>
            <img src="images/men.png" class="preguntaContent"><br>
            <div class="operator" onclick="restar()">-</div><div id="numberOfDwellers">1</div><div class ="operator" onclick="
```

```
            sumar()">+</div>
        </div>
        <div class = "pregunta">
            <div class="textPregunta">How big is the house?</div>
            <img src="images/house.png" class="preguntaContent"><br>
            <div class="operator" onclick="restar10()">-</div><div id="houseSize">50</div><div class ="operator" onclick="sumar10()">+</div>
        </div>
        <div class = "pregunta">
            <div class="textPregunta">When do you use electricity the most?</div>
            Morning<input type="checkbox" id="selfConsumptionM"><br>
            Afternoon<input type="checkbox" id="selfConsumptionA"><br>
            Night<input type="checkbox" id="selfConsumptionN">
        </div>
        <div class = "pregunta">
            <div class="textPregunta">Check the boxes if you have:</div>
            Electric space heating <input type="checkbox" id="spaceHeating"><br>
            Electric water heating <input type="checkbox" id="hotWater">
        </div>
        <div class = "pregunta">
            <div class="textPregunta">What is the slope of your roof?</div>
            <img id="teulada" src="images/line.png"><p id="angleTeulada">0  </p><br>
            <input type="range" min="0" max="50" value="0" class="slider" id="myRange" oninput="rotar()">
        </div>
        <div class = "pregunta">
            <div class="textPregunta">What direction is your roof facing?</div>
            <img id="teulada2" src="images/arrow.png"><p id="direccioTeulada">S</p><br>
            <input type="range" min="0" max="360" value="0" class="slider" id="myRange2" oninput="rotar2()">
        </div>
        <div id="submitButton">Submit</div>
    </div>

    <div id="output">Here's your personalized solar system located in<b id="coordinates"></b>
        <div id="whiteSpace"></div>
        <div id = "breakdown">
            <div class="panels">
                <div class="outputPanels" id="pvPanel">
                    <div class="panelNumber" id="numberOne">0</div>
                    <div class="technicalSheet" id="technicalSheetOne">PV panels<br><a href="pdf/pvDataSheet.pdf" target="_blank"><small>See datasheet</small></a></div>
                </div>
                <div class="outputPanels" id="thermalPanel">
                    <div class="panelNumber" id="numberTwo">0</div>
                    <div class="technicalSheet" id="technicalSheetTwo">
```

```
                        Thermal panels<br><a href="pdf/thermalDataSheet.
                        PDF" target="_blank"><small>See datasheet</small>
                        </a></div>
                </div>
                <div class="outputPanels" id="hybridPanel">
                    <div class="panelNumber" id="numberThree">0</div>
                    <div class="technicalSheet" id="technicalSheetThree"
                        >Hybrid panels<br><a href="pdf/hybridDataSheet.
                        pdf" target="_blank"><small>See datasheet</small>
                        </a></div>
                </div>
            </div>
            <div id="whiteSpace"></div>
            <div id="prova">
                <div class="investmentFigures" id ="price"></div>
                <div class="investmentFigures" id="profit"></div>
                <div class="investmentFigures" id="energy"></div>
            </div>
            <br>
            <div id="prova">
                <div class="investmentFigures"><b>Power</b></div>
                <div class="investmentFigures" id ="KWp"></div>
                <div class="investmentFigures" id="KWt"></div>
            </div>
            <br>
            <div id="divChart"></div>

        </div>
    </div>
</body>
</html>
```

JavaScript code

```

let myMap = L.map('myMap', {zoomControl: false }).setView([41.3851,
    2.1734], 13);

var satImg = L.gridLayer.googleMutant({ type: 'satellite' }).addTo(myMap
    );

myMap.pm.addControls({
    position: 'topleft',
    drawCircle: false,
    drawRectangle: false,
    drawPolyline: false,
    drawMarker: false,
    drawCircleMarker: false,
    editMode: false,
    cutPolygon: false,
});

L.control.scale().addTo(myMap);

myMap.pm.enableDraw('Polygon', {
```

```
    snappable: true,
    snapDistance: 20,
});

L.Control.geocoder({
    collapsed: true,
    expand: "click",
    position: "topleft"

}).addTo(myMap);

var roofSize = 0;
var coord1 = 0;
var coord2 = 0;

myMap.on('pm:create', e => {
    const layer = e.layer;
    roofSize = (turf.area(layer.toGeoJSON())).toFixed(2);
    console.log(layer.toGeoJSON());
    coord1 = layer.toGeoJSON().geometry.coordinates[0][0][0];
    coord2 = layer.toGeoJSON().geometry.coordinates[0][0][1];

    var xhttp = new XMLHttpRequest();
    xhttp.onreadystatechange = function() {
    if (this.readyState == 4 && this.status == 200) {
        ESHString = xhttp.responseText;

        }
    };

    var lat = coord2.toString();
    var lon = coord1.toString();

    xhttp.open("GET", "https://re.jrc.ec.europa.eu/api/mrcalc?lat=" + lat + "&lon=" + lon + "&startyear=2016&selectrad=1&angle=50", true);
    xhttp.send();

    document.getElementById("myMap").style.transition = "all 1s";

    document.getElementById("myMap").style.zIndex = -1;
    document.getElementById("myMap").style.opacity = 0;
    document.getElementById("myMap").style.pointerEvents = "none";
});

var north = L.control({position: "topright"});
north.onAdd = function(map) {
    var div = L.DomUtil.create("div", "info legend");
    div.innerHTML = '<img src="images/northArrow.jpg" style="height: 10vh;">';
    return div;
}
north.addTo(myMap);

var submitButton = document.getElementById("submitButton");
```

```

var ESHstring = "";

var info = document.getElementById("info");
var solarDetails = document.getElementById("solarDetails")
var demo = document.getElementById("demo");

// PV calculations
//Assumptions related to energy

var panelPower = 370;
var panelSize = 1.75;
var panelPrice = 240;
var percentageOfSystemPrice = 0.58;

//Assumptions related to money

var initialInvestment = -1 * panelPrice/(panelSize*percentageOfSystemPrice);
var electricityPrice = 0.15;
var futurePrice = [];
var surplusPrice = 0.03;
var futureSurplusPrice = [];
var interestRate = 0.02;
var IPC = 0.02;
var investmentTime = 25;

//Computation of electricity and surplus prices for the full investment time

for (i = 0; i < investmentTime + 1; i++){
    futurePrice.push(electricityPrice*Math.pow(1 + IPC, i));
    futureSurplusPrice.push(surplusPrice*Math.pow(1 + IPC, i));
}

//Cash flow function, returns an array with the cashflow of every period

function cashFlowPV(e, p, self, ps, r, t, inv){

    var yearlyCashFlow = [inv + e*p[0]*self + e*ps[0]*(1 - self)];

    for (i = 1; i < t + 1; i++){
        yearlyCashFlow.push((e*p[i]*self + e*ps[i]*(1 - self))/Math.pow((1 + r), i));
    };

    return yearlyCashFlow
};

//Thermal calculations
//Assumptions related to energy

var panelEffT = 0.65;
var panelSizeT = 2.62;
var panelPriceT = 377.22;
```

```
var percentageOfSystemPriceT = 0.38;

//Assumptions related to money

var initialInvestmentT = -1 * panelPriceT/(panelSizeT*
    percentageOfSystemPriceT);
var gasPriceF = 0.061;
var gasPriceS = 0.054;
var futureGasPriceF = [];
var futureGasPriceS = [];

//Computation of future gas prices for the full investment time and the
    two regulated tariffs (F (first) for TUR1 and S (second) for TUR2)

for (i = 0; i < investmentTime + 1; i++){
    futureGasPriceF.push(gasPriceF*Math.pow(1 + IPC, i));
    futureGasPriceS.push(gasPriceS*Math.pow(1 + IPC, i));
}

//Cash flow function, returns an array with the cashflow of every period

function cashFlowT(wD, sD, p, n, s, r, t, inv){
    var yearlyCashFlow = [inv + ((wD+sD)*p[0])/(n*s)];

    for (i = 1; i < t + 1; i++){
        yearlyCashFlow.push((((wD+sD)*p[i])/(n*s))/Math.pow((1 + r), i))
            ;
    };

    return yearlyCashFlow
};


//Hybrid calculations
//Assumptions related to energy

var panelPowerH = 350;
var panelEffH = 0.53;
var panelSizeH = 1.96;
var panelPriceH = 568 * 0.7;
var percentageOfSystemPriceH = 0.5676;

//Assumptions related to money
var initialInvestmentH = -1 *panelPriceH/(panelSizeH *
    percentageOfSystemPriceH);

function cashFlowH(e, pe, self, ps, wD, sD, pg, n, s, r, t, inv){
    var yearlyCashFlow = [inv +  e*pe[0]*self + e*ps[0]*(1 - self) + ((
        wD+sD)*pg[0])/(n*s)];
    for (i = 1; i < t + 1; i++){
        yearlyCashFlow.push((((wD+sD)*pg[i])/(n*s) + (e*pe[i]*self + e*
            ps[i]*(1 - self)))/Math.pow((1 + r), i));
    };

    return yearlyCashFlow
```

```
}

//Function to caclulate the cashflow for the definitive system

function totalCashFlow(e, pe, self, ps, tE, pg, r, t, inv){
    var yearlyCashFlow = [-inv +  e*pe[0]*self + e*ps[0]*(1 - self) + tE*pg[0]];
    for (i = 1; i < t + 1; i++){
        yearlyCashFlow.push((tE*pg[i] + (e*pe[i]*self + e*ps[i]*(1 - self)))/Math.pow((1 + r), i));
    };

    return yearlyCashFlow
}

function rotar(){
    var value = document.getElementById("myRange").value;
    var angle = value.toString();
    document.getElementById("angleTeulada").innerHTML = angle + "  ";
    document.getElementById("teulada").style.webkitTransform = "rotate(-" + angle + "deg)";
}

function rotar2(){
    var value = document.getElementById("myRange2").value;
    var angle = value.toString();
    var direccio = "";
    if (angle < 30)
        direccio = "S";
    else if (angle >= 30 && angle < 60)
        direccio = "SE";
    else if (angle >= 60 && angle < 120)
        direccio = "E";
    else if (angle >= 120 && angle < 150)
        direccio = "NE";
    else if (angle >= 150 && angle < 210)
        direccio = "N";
    else if (angle >= 210 && angle < 240)
        direccio = "NW";
    else if (angle >= 240 && angle < 300)
        direccio = "W";
    else if (angle >= 300 && angle < 330)
        direccio = "SW";
    else
        direccio = "S";

    document.getElementById("direccioTeulada").innerHTML = direccio;
    document.getElementById("teulada2").style.webkitTransform = "rotate(-" + angle + "deg)";
}

function sumar(){
    var value = parseInt(document.getElementById("numberOfDwellers").innerHTML);
    document.getElementById("numberOfDwellers").innerHTML = value + 1;
```

```
}

function restar(){
    var value = parseInt(document.getElementById("numberOfDwellers").innerHTML);
    if (value == 0)
        return
    document.getElementById("numberOfDwellers").innerHTML = value - 1;
}

function sumar10(){
    var value = parseInt(document.getElementById("houseSize").innerHTML);
    document.getElementById("houseSize").innerHTML = value + 10;
}

function restar10(){
    var value = parseInt(document.getElementById("houseSize").innerHTML);
    if (value == 0)
        return
    document.getElementById("houseSize").innerHTML = value - 10;
}


submitButton.onclick = function(){

    document.getElementById("preguntes").style.display = "none";

    //We fetch the variables and make sure that at least one of the electricity consumption periods is checked
    var selfConsumptionM = document.getElementById("selfConsumptionM");
    var selfConsumptionA = document.getElementById("selfConsumptionA");
    var selfConsumptionN = document.getElementById("selfConsumptionN");
    var spaceHeating = document.getElementById("spaceHeating");
    var hotWater = document.getElementById("hotWater");
    var roofSlope = document.getElementById("myRange").value;
    var roofOrientation = document.getElementById("myRange2").value;

    roofSlope = roofSlope*Math.PI/180;

    var exploitationFactor = Math.sin(50*Math.PI/180-roofSlope)/Math.tan(25*Math.PI/180 + roofSlope) + Math.cos(50*Math.PI/180-roofSlope);

    panelSize = 1.75 * exploitationFactor;
    panelSizeH = 1.96 * exploitationFactor;
    panelSizeT = 2.62 * exploitationFactor;

    initialInvestment = -1 * panelPrice/(panelSize * percentageOfSystemPrice);
    initialInvestmentT = -1 * panelPriceT/(panelSizeT * percentageOfSystemPriceT);
    initialInvestmentH = -1 * panelPriceH/(panelSizeH * percentageOfSystemPriceH);
```

```
    if (roofOrientation < 210 && roofOrientation > 150){
        return alert("We do not recommend you to place panels in this
            roof because it is facing north");
    }
    var alpha = 0;

    if (roofOrientation < 150){
        alpha = roofOrientation * - 1;
    }
    else{
        alpha = (roofOrientation - 360) * - 1;
    }

    var orientationFactor = 1 - (0.000035 * Math.pow(alpha, 2));



    //We need to go through ESHString to find the monthly values and
        store them in an array
    var helpArray = [];
    var helpString = ESHString.split("\n");

    //The data is found in rows 5-16 and the ESH values after the 11th
        character in each row

    for (i = 5; i < 17; i++){
        helpArray.push(helpString[i].slice(11));
    };

    var arrayESH = helpArray;
    arrayESH = arrayESH.map(Number);

    var sC = 0;

    if (selfConsumptionM.checked == true)
        sC += 0.3;
    if (selfConsumptionA.checked == true)
        sC += 0.3;
    if (selfConsumptionN.checked == true)
        sC += 0.1;
    if (sC == 0){
        return alert("Check at least one period of electricity
            consumption")
    }

    var ESH = (arrayESH.reduce((a,b) => a + b, 0)/365).toFixed(2);
    //showESH.innerHTML = ESH;
    //showRoofSize.innerHTML = roofSize;
    var numberOfDwellers = parseInt(document.getElementById("
        numberOfDwellers").innerHTML);
    //showDwellers.innerHTML = numberOfDwellers;
    var houseSize = parseFloat(document.getElementById("houseSize").
        innerHTML);
    //showHouseSize.innerHTML = houseSize;
```

```
    //showSelfConsumption.innerHTML = sC;

    //Calculation of generated electricity for PV

    var generatedElectricity = orientationFactor * 0.001 * ESH * 365 * panelPower/panelSize;

    //Calculation of the Cash Flow array for PV

    var yearlyValue = cashFlowPV(generatedElectricity, futurePrice, sC, futureSurplusPrice, interestRate, investmentTime, initialInvestment);

    var vanPV = (yearlyValue.reduce((a,b) => a + b, 0)).toFixed(2);

    //Calculation of the internal rate of return with a 0.01 error margin.

    var interestIRR = 0;

    while (cashFlowPV(generatedElectricity, futurePrice, sC, futureSurplusPrice, interestIRR, investmentTime, initialInvestment).reduce((a,b) => a + b, 0) > 0){
        interestIRR += 0.0001;
    }

    var IRR = (interestIRR * 100).toFixed(2);

    //Calculation of generated thermal energy potential per square metre
    var ESHWinter = ((arrayESH[1] + arrayESH[2] + arrayESH[3] + arrayESH[10] + arrayESH[11])/151).toFixed(2);
    panelEffT = 0.65 / exploitationFactor;
    var tEnergyWinter = orientationFactor * (ESHWinter) * panelEffT;
    var tEnergySummer = ESH * panelEffT;

    //Calculation of thermal demands

    var avgWinterDemand = 53.61 * houseSize/(5 * 30.5) + 1.91 * numberOfDwellers;
    var avgSummerDemand = 1.91 * numberOfDwellers;

    //Adapt demands to checkboxes about energy source
    var electricityDemand = 0;

    if (spaceHeating.checked == true){
        avgWinterDemand = avgWinterDemand - 53.61 * houseSize/(5 * 30.5);
        electricityDemand += 53.61 * houseSize;
    }

    if (hotWater.checked == true){
        avgWinterDemand = avgWinterDemand - 1.91 * numberOfDwellers;
        avgSummerDemand = avgSummerDemand - 1.91 * numberOfDwellers;
        electricityDemand += 1.91 * numberOfDwellers * 365;
    }
```

```

    if (avgWinterDemand < 1){
        avgWinterDemand = 0;
    }

    if (avgSummerDemand < 1){
        avgSummerDemand = 0;
    }


    var totalWinterDemand = avgWinterDemand * 30.5 * 5;
    var totalSummerDemand = avgSummerDemand * 30.5 * 7;
    var totalDemand = Math.floor(totalWinterDemand + totalSummerDemand);

    //Calculation of system size

    var tSystemSize = avgWinterDemand/tEnergyWinter;
    var numberOfPanelsT = Math.floor(tSystemSize/panelSizeT);

    //Determination of the appropiate regulated tariff

    if (totalDemand < 5000)
        var gasPrice = futureGasPriceF;
    else
        var gasPrice = futureGasPriceS;

    var vanT = 0;
    var interestIRRT = 0;
    var IRRT = 0;

    //Calculation of the Cash Flow array for thermal energy
    if (numberOfPanelsT <= 0){

    }

    else{
        var yearlyValueT = cashFlowT(totalWinterDemand,
           totalSummerDemand, gasPrice, numberOfPanelsT, panelSizeT,
           interestRate, investmentTime, initialInvestmentT);
        vanT = (yearlyValueT.reduce((a,b) => a + b, 0)).toFixed(2);

        if (vanT < initialInvestmentT){

        }

        else{
            while (cashFlowT(totalWinterDemand, totalSummerDemand,
               gasPrice, numberOfPanelsT, panelSizeT, interestIRRT,
               investmentTime, initialInvestmentT).reduce((a,b) => a + b
               , 0) > 0){
                interestIRRT += 0.0001;
            };

            IRRT = (interestIRRT * 100).toFixed(2);
        }
```

```
    }

    //Calculation of the generated electricity and thermal energy for hybrid

    var generatedElectricityH = orientationFactor * 0.001 * ESH * 365 * panelPowerH/panelSizeH;
    panelEffH = 0.53 / exploitationFactor;

    var tEnergyWinterH = orientationFactor * (tEnergyWinter/panelEffT)* panelEffH;
    var tSystemSizeH = avgWinterDemand/tEnergyWinterH;

    //Calculation of the Cash Flow array for the hybrid technology
    ;
    var numberOfPanelsH = Math.floor(tSystemSizeH/panelSizeH);
    var yearlyValueH = 0;

    var vanH = 0;
    var interestIRRH = 0;

    if (numberOfPanelsH <= 0){
        yearlyValueH = cashFlowPV(generatedElectricityH, futurePrice, sC, futureSurplusPrice, interestRate, investmentTime, initialInvestmentH);
    }
    else{
        yearlyValueH = cashFlowH(generatedElectricityH, futurePrice, sC, futureSurplusPrice, totalWinterDemand, totalSummerDemand, gasPrice, numberOfPanelsH, panelSizeH, interestRate, investmentTime, initialInvestmentH);
    }

    var vanH = (yearlyValueH.reduce((a,b) => a + b, 0)).toFixed(2);

    if (numberOfPanelsH <= 0){
        while (cashFlowPV(generatedElectricityH, futurePrice, sC, futureSurplusPrice, interestIRRH, investmentTime, initialInvestmentH).reduce((a,b) => a + b, 0) > 0){
            interestIRRH += 0.0001;
        };
    }
    else{
        while (cashFlowH(generatedElectricityH, futurePrice, sC, futureSurplusPrice, totalWinterDemand, totalSummerDemand, gasPrice, numberOfPanelsH, panelSizeH, interestIRRH, investmentTime, initialInvestmentH).reduce((a,b) => a + b, 0) > 0){
            interestIRRH += 0.0001;
        };
    }

    var IRRH = (interestIRRH * 100).toFixed(2);

    var solarSystem = [0, 0, 0];
```

```

    electricityDemand = electricityDemand + 1516 * numberOfDwellers;
    var dailyElectricityDemand = electricityDemand/365;
    var requiredPower = 1000 * dailyElectricityDemand/(ESH *
        orientationFactor);

    if (Math.max(IRR, IRRT, IRRH) == IRR){
        solarSystem[0] = Math.floor(requiredPower/panelPower);
        if (solarSystem[0] * panelSize > roofSize){
            solarSystem[0] = Math.floor(roofSize/panelSize);
        }
        else{
            solarSystem[1] = Math.floor((avgWinterDemand/tEnergyWinter)/
                panelSizeT);
            if ((solarSystem[1] * panelSizeT + solarSystem[0] *
                panelSize) > roofSize){
                solarSystem[1] = Math.floor((roofSize - solarSystem[0] *
                    panelSize)/panelSizeT)
            }
        }
    }
    if (Math.max(IRR, IRRT, IRRH) == IRRT){
        solarSystem[1] = Math.floor((avgWinterDemand/tEnergyWinter)/
            panelSizeT);
        if (solarSystem[1] * panelSizeT > roofSize){
            solarSystem[1] = Math.floor(roofSize/panelSizeT);
        }
        else{
            solarSystem[0] = Math.floor(requiredPower/panelPower);
            if ((solarSystem[1] * panelSizeT + solarSystem[0] *
                panelSize) > roofSize){
                solarSystem[0] = Math.floor((roofSize - solarSystem[1] *
                    panelSizeT)/panelSize)
            }
        }
    }

    var nPanelsPV = 0;
    var nPanelsT = 0;

    if (Math.max(IRR, IRRT, IRRH) == IRRH){

        nPanelsPV = Math.floor(requiredPower/panelPowerH);
        nPanelsT = Math.floor(tSystemSizeH/panelSizeH);

        solarSystem[2] = Math.min(nPanelsPV,nPanelsT);

        if (solarSystem[2] == nPanelsT){
            if (solarSystem[2] * panelSizeH > roofSize){
                solarSystem[2] = Math.floor(roofSize/panelSizeH);
            }
            else{
                solarSystem[0] = Math.floor((requiredPower - panelPowerH
                    *nPanelsT)/panelPower)
                if ((solarSystem[0] * panelSize + solarSystem[2] *
```

```
                    panelSizeH) > roofSize){
                    solarSystem[0] = Math.floor((roofSize - nPanelsT * panelSizeH)/panelSize);
                }
            }
        }
        else{
            if (solarSystem[2] * panelSizeH > roofSize){
                solarSystem[2] = Math.floor(roofSize/panelSizeH);
            }
            else{
                var tEnergyNeed = avgWinterDemand - solarSystem[2] * panelSizeH * tEnergyWinterH;
                solarSystem[1] = Math.floor((tEnergyNeed/tEnergyWinter)/panelSizeT);
                if ((solarSystem[1] * panelSizeT + solarSystem[2] * panelSizeH) > roofSize){
                    solarSystem[1] = Math.floor((roofSize - solarSystem[2]*panelSizeH)/panelSizeT);
                }
            }
        }
    }

    var output = document.getElementById("output");
    output.style.display = "block";
    output.style.opacity = "1";

    var coordinates = document.getElementById("coordinates");
    coordinates.innerHTML = coordinates.innerHTML + " " + coord2 + ", " + coord1;

    var totalPrice = solarSystem[0]*panelPrice/percentageOfSystemPrice + solarSystem[1]*panelPriceT/percentageOfSystemPriceT + solarSystem[2]*panelPriceH/percentageOfSystemPriceH;
    totalPrice = totalPrice.toFixed(2);

    var realGeneratedElectricity = orientationFactor * (solarSystem[0] * panelPower * ESH * 365 / 1000 + solarSystem[2] * panelPowerH * ESH * 365 / 1000);
    var realThermalEnergy = solarSystem[1] * panelEffT * panelSizeT * ESHWinter * 151;
    realThermalEnergy += solarSystem[2] * panelEffH * panelSizeH * ESHWinter * 151;
    realThermalEnergy += avgSummerDemand * 214;
    realThermalEnergy = orientationFactor * realThermalEnergy;

    var systemCashFlow = totalCashFlow(realGeneratedElectricity, futurePrice, sC, futureSurplusPrice, realThermalEnergy, gasPrice, interestRate, investmentTime, totalPrice);

    for (i = 1; i < investmentTime + 1; i++){
        systemCashFlow[i] = systemCashFlow[i] + systemCashFlow[i - 1];
    }

```

```

    if (solarSystem[0] == 0){

    }
    else{
        document.getElementById("pvPanel").style.display = "inline-block";
        document.getElementById("numberOne").innerHTML = solarSystem[0];
    }

    if (solarSystem[1] == 0){

    }
    else{
        document.getElementById("thermalPanel").style.display = "inline-block";
        document.getElementById("numberTwo").innerHTML = solarSystem[1];
    }

    if (solarSystem[2] == 0){

    }
    else{
        document.getElementById("hybridPanel").style.display = "inline-block";
        document.getElementById("numberThree").innerHTML = solarSystem[2];
    }



    var colors = [];

    for (i = 0; i < investmentTime + 1; i++){
        if (systemCashFlow[i] < 0){
            colors.push("#EC7063 ");
        }
        else{
            colors.push("#52BE80");
        }
    }

    var chart = new CanvasJS.Chart("divChart", {

        theme: "light1",

    data: [
    {
            type: "column",
            color: "#062247",
      dataPoints: [
        { label: "0",  y: systemCashFlow[0], color: colors[0]  },
        { label: "1", y: systemCashFlow[1], color: colors[1]  },
        { label: "2", y: systemCashFlow[2], color: colors[2]  },
        { label: "3",  y: systemCashFlow[3], color: colors[3]  },
```

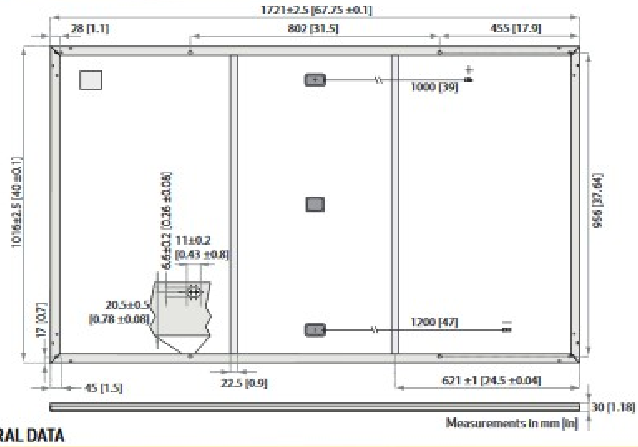
```
                { label: "4",  y: systemCashFlow[4], color: colors[4] },
                { label: "5",  y: systemCashFlow[5], color: colors[5] },
        { label: "6", y: systemCashFlow[6], color: colors[6]  },
        { label: "7", y: systemCashFlow[7], color: colors[7]  },
        { label: "8",  y: systemCashFlow[8], color: colors[8]  },
                { label: "9",  y: systemCashFlow[9], color: colors[9] },
                { label: "10",  y: systemCashFlow[10], color: colors[10] },
        { label: "11", y: systemCashFlow[11], color: colors[11]  },
        { label: "12", y: systemCashFlow[12], color: colors[12]  },
        { label: "13",  y: systemCashFlow[13], color: colors[13]  },
                { label: "14",  y: systemCashFlow[14], color: colors[14] },
                { label: "15",  y: systemCashFlow[15], color: colors[15] },
                { label: "16",  y: systemCashFlow[16], color: colors[16] },
        { label: "17", y: systemCashFlow[17], color: colors[17]  },
        { label: "18", y: systemCashFlow[18], color: colors[18]  },
        { label: "19",  y: systemCashFlow[19], color: colors[19]  },
                { label: "20",  y: systemCashFlow[20], color: colors[20] },
                { label: "21",  y: systemCashFlow[21], color: colors[21] },
        { label: "22", y: systemCashFlow[22], color: colors[22]  },
        { label: "23", y: systemCashFlow[23], color: colors[23]  },
        { label: "24",  y: systemCashFlow[24], color: colors[24]  },
      ]
    }
    ]
  });
    chart.render();

    var totalEnergy = realGeneratedElectricity + realThermalEnergy;

    document.getElementById("price").innerHTML = "Cost " + "<b>" + totalPrice + "    </b>";
    document.getElementById("profit").innerHTML = "Profit " + "<b>" + systemCashFlow[24].toFixed(2) + "    </b>";
    document.getElementById("energy").innerHTML = "Generation " + "<b>" +  totalEnergy.toFixed(2) + " kWh/year</b>";
    document.getElementById("KWp").innerHTML = solarSystem[0] * 0.37 + solarSystem[2]*0.35 + " KWp";
    document.getElementById("KWt").innerHTML = solarSystem[1]*1.65 + solarSystem[2]*1.06 + " KWt";
};
```

II Datasheets

REC ALPHA SERIES
PRODUCT DATASHEET



CERTIFICATIONS

IEC 61215:2016, IEC 61730:2016, UL 1703, UL 61730

IEC 62804	PID
IEC 61701	Salt Mist
IEC 62716	Ammonia Resistance
UL 1703	Fire Type Class 2
IEC 62782	Dynamic Mechanical Load
IEC 61215-2:2016	Hailstone (35mm)
AS4040.2 NCC 2016	Cyclic Wind Load

ISO 14001:2004, ISO 9001:2015, OHSAS 18001:2007

WARRANTY

20 year product warranty
25 year linear power output warranty
Maximum annual power degression of 0.25% p.a.
Guarantees 92% of power after 25 years
See warranty conditions for further details.

MECHANICAL DATA

Dimensions:	67.8 x 40 x 1.2 in (1721 x 1016 x 30 mm)
Area:	18.8 sq ft (1.75 m^2)
Weight:	43 lbs (19.5 kg)

GENERAL DATA

Cell type:	120 half-cut cells with REC heterojunction cell technology 6 strings of 20 cells in series	Junction box:	3-part, 3 bypass diodes, IP67 rated in accordance with IEC 62790
Glass:	0.13 in (3.2 mm) solar glass with anti-reflection surface treatment	Cable:	12 AWG (4 mm^2) PV wire, 39 + 47 in (1 + 1.2 m) in accordance with EN 50618
Backsheet:	Highly resistant polymeric construction	Connectors:	Staubli MC4 PV-KBT4/KST4, 12 AWG (4 mm^2) in accordance with IEC 62852 IP68 only when connected
Frame:	Anodized aluminum (black)	Origin:	Made in Singapore

MAXIMUM RATINGS

Operational temperature:	-40 ... +85°C
Maximum system voltage:	1000 V
Design load (+): snow	4666 Pa (97.5 lbs/sq ft)*
Maximum test load (+):	7000 Pa (146 lbs/sq ft)*
Design load (-): wind	2666 Pa (55.6 lbs/sq ft)*
Maximum test load (-):	4000 Pa (83.5 lbs/sq ft)*
Max series fuse rating:	25 A
Max reverse current:	25 A

* Calculated using a safety factor of 1.5
* See installation manual for mounting instructions

ELECTRICAL DATA @ STC — Product Code*: RECxxxAA

Nominal Power - P_{MPP} (Wp)	360	365	370	375	380
Watt Class Sorting - (W)	-0/+5	-0/+5	-0/+5	-0/+5	-0/+5
Nominal Power Voltage - V_{MPP} (V)	37.7	38.0	38.3	38.7	39.0
Nominal Power Current - I_{MPP} (A)	9.55	9.60	9.66	9.72	9.76
Open Circuit Voltage - V_{OC} (V)	44.1	44.3	44.5	44.6	44.7
Short Circuit Current - I_{SC} (A)	10.23	10.26	10.30	10.40	10.46
Panel Efficiency (%)	20.6	20.9	21.2	21.4	21.7

Values at standard test conditions (STC: air mass AM 1.5, irradiance 10.75 W/sq ft (1000 W/m^2), temperature 77°F (25°C), based on a production spread with a tolerance of V_{OC} & I_{SC} ±3% within one watt class. * Where xxx indicates the nominal power class (P_{MPP}) at STC above.

TEMPERATURE RATINGS*

Nominal Module Operating Temperature:	44°C (±2°C)
Temperature coefficient of P_{MPP}:	-0.26 %/°C
Temperature coefficient of V_{OC}:	-0.24 %/°C
Temperature coefficient of I_{SC}:	0.04 %/°C

*The temperature coefficients stated are linear values

Specifications subject to change without notice.

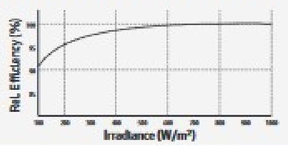
ELECTRICAL DATA @ NMOT — Product Code*: RECxxxAA

Nominal Power - P_{MPP} (Wp)	274	278	282	286	290
Nominal Power Voltage - V_{MPP} (V)	35.5	35.8	36.1	36.4	36.7
Nominal Power Current - I_{MPP} (A)	7.71	7.76	7.80	7.85	7.88
Open Circuit Voltage - V_{OC} (V)	41.6	41.7	41.9	42.0	42.1
Short Circuit Current - I_{SC} (A)	8.26	8.29	8.32	8.40	8.45

Nominal module operating temperature (NMOT: air mass AM 1.5, irradiance 800 W/m^2, temperature 68°F (20°C), windspeed 3.3 ft/s (1 m/s). * Where xxx indicates the nominal power class (P_{MPP}) at STC above.

LOW LIGHT BEHAVIOUR

Typical low irradiance performance of module at STC:



Ref: PM-DS-12-01-Rev- B 08.19

Founded in Norway in 1996, REC is a leading vertically integrated solar energy company. Through integrated manufacturing from silicon to wafers, cells, high-quality panels and extending to solar solutions, REC provides the world with a reliable source of clean energy. REC's renowned product quality is supported by the lowest warranty claims rate in the industry. REC is a Bluestar Elkem company with headquarters in Norway and operational headquarters in Singapore. REC employs around 2,000 people worldwide, producing 1.5 GW of solar panels annually.

REC
www.recgroup.com

Figure II.I: Rec Alpha PV panel datasheet

ETSEIB

ECOTOP VHM N

CAPTADOR SOLAR PLANO SELECTIVO
DE ALTO RENDIMIENTO

EST Energía Solar Térmica Ferroli

Garantía 5 años en componentes hidráulicos

Producción A.C.S., calentamiento de piscinas, calefacción baja temperatura, fancoils y refrigeración por absorción

Captadores solares fabricados bajo las siguientes normas:

– Pruebas de certificación según EN-12975-2.

– Contraseña de Certificación por la Dirección General de Política Energética y Minas.

VENTAJAS del captador ECOTOP VHM N:

- Se pueden conectar hasta 8 captadores por batería.
- La cubierta es de vidrio templado de bajo contenido en hierro (inferior al 0,005%), de 3,2 mm de espesor.
- La carcasa exterior es de aluminio.
- La superficie de absorción es de aluminio con recubrimiento selectivo y con tratamiento de óxido de titanio.
- La placa colectora es de tubos de cobre.
- El aislamiento es de lana de roca de 40 mm de espesor.
- El captador tiene garantía contra defectos de fabricación de 5 años:
  – Las conexiones de entrada y salida son de 3/4" (4 conexiones).

El rendimiento de un captador se define como el cociente entre la energía obtenida del captador y la energía máxima posible generada:

$$\eta = \frac{Q_u}{A \times I}$$

Q_u= Energía útil en el captador (W)

A= Área de referencia (m^2)

I= Irradiación solar (W/m^2)

La curva de rendimiento homologada del captador ECOTOP VHM N se define por tres coeficientes, y está referida normalmente al área de apertura:

- **El factor de ganancia (o factor de eficiencia): η_0.**
- **Coeficiente global de pérdidas de primer grado a_1.**
- Coeficiente global de pérdidas de segundo grado a_2.

Valores referentes a superficie de apertura	VHM 2.7 N
η_0	0,753
a_1 (W/m^2K)	3,168
a_2 (W/m^2K)	0,012

Ferroli

Figure II.II: Ferroli thermal panel datasheet p. 1

ETSEIB

ECOTOP VHM N

CAPTADOR SOLAR PLANO SELECTIVO DE ALTO RENDIMIENTO

Captador solar para una óptima utilización en toda la Península Ibérica

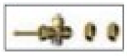
Para el cálculo de la pérdida de carga por captador solar*, sabiendo que el caudal máximo de trabajo recomendado suele ser inferior a 2 litros/minuto, se proporciona la caída de presión para cada captador:

Caudal recomendado (l/h) 100-200

Pérdida carga estimada media por captador*				
Caudal (litros/min captador)	3	2	1	0
Pérdida de carga (Pa)	2500	1650	1000	0

* Caudal recomendado de trabajo ≤ 2 litros/min.

ACCESORIOS PARA CAPTADOR ECOTOP VHM N

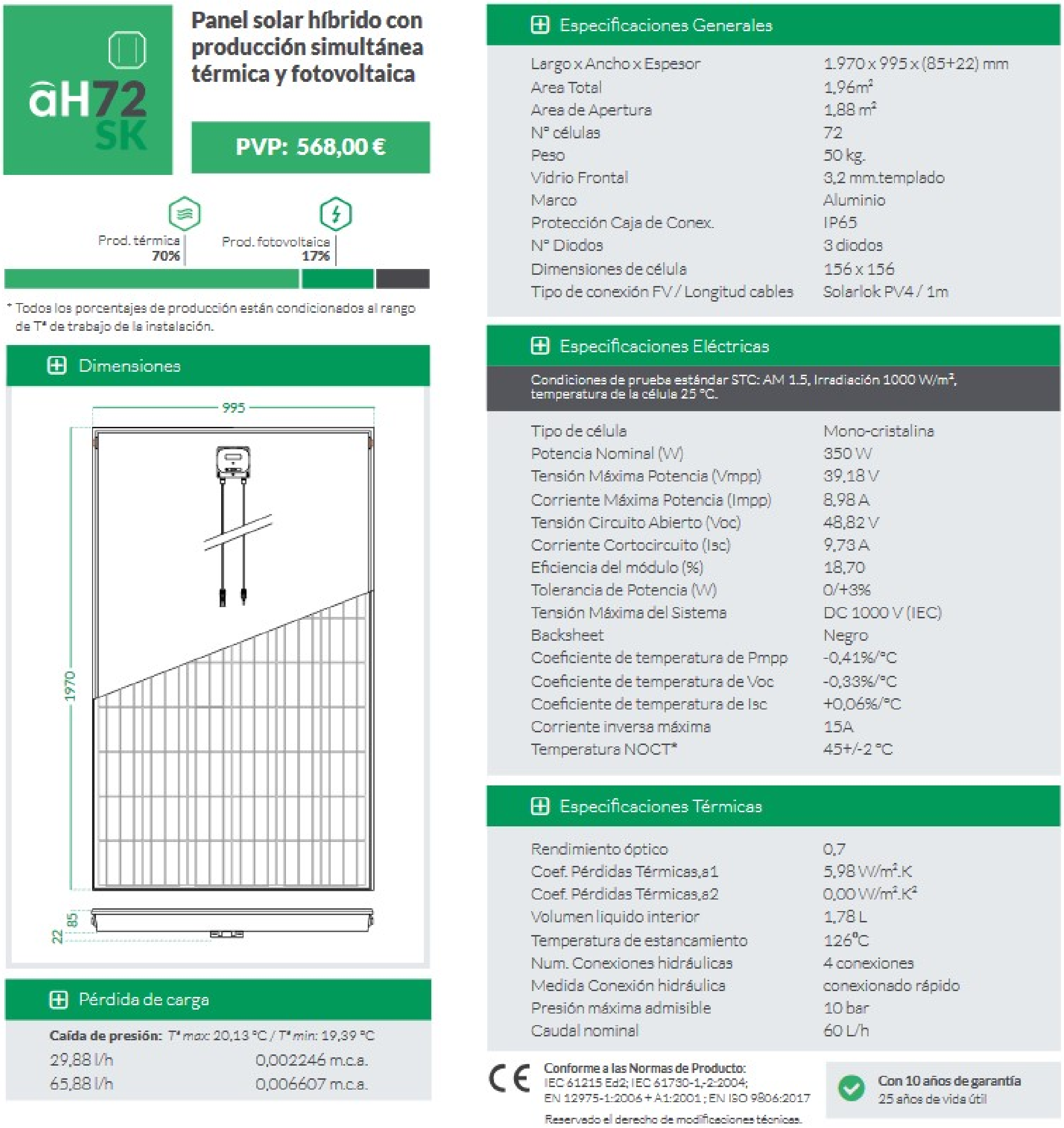
	Descripción	CÓDIGO	Observaciones
	Kit 4 conexiones, incluye: • 2 tapones de cierre; • Conexión entrada paneles; • Conexión salida panel con vaina;	C51022590	OBLIGATORIO Es obligatorio usar N kits por cada N filas de captadores
	Kit conexiones intermedias.	C51022600	OBLIGATORIO Es obligatorio usar N-1 kits por cada fila de N captadores

		VHM 2.7 N
Superficie total	m^2	2,62
Superficie de apertura	**m^2**	**2,47**
Altura	mm	2.022
Ancho	mm	1.294
Fondo	mm	90
Número de conexiones		4
Diámetro conexiones (roscadas macjo)	"	3/4
Peso en vacío	Kg	41,8
Contenido fluido	l	1,1
Caudal de trabajo recomendado	l/h	75-150
Presión máx. de trabajo	bar	10
Temperatura de estancamiento	°C	201,2
Aislamiento en lana de roca de espesor	mm	40
Grado de absorción	%	95
Emisividad	%	5
Máximo número de colectores en paralelo		**8**
CÓDIGO		0XDP2KXA

Ferroli

245

Figure II.III: Ferroli thermal panel datasheet p. 2



Panel solar híbrido con producción simultánea térmica y fotovoltaica

âH72 SK

PVP: 568,00 €

Prod. térmica 70%

Prod. fotovoltaica 17%

* Todos los porcentajes de producción están condicionados al rango de T* de trabajo de la instalación.

Especificaciones Generales

Largo x Ancho x Espesor	1.970 x 995 x (85+22) mm
Area Total	1,96m²
Area de Apertura	1,88 m²
Nº células	72
Peso	50 kg.
Vidrio Frontal	3,2 mm.templado
Marco	Aluminio
Protección Caja de Conex.	IP65
Nº Diodos	3 diodos
Dimensiones de célula	156 x 156
Tipo de conexión FV / Longitud cables	Solarlok PV4 / 1m

Dimensiones

Especificaciones Eléctricas

Condiciones de prueba estándar STC: AM 1.5, Irradiación 1000 W/m², temperatura de la célula 25 °C.

Tipo de célula	Mono-cristalina
Potencia Nominal (W)	350 W
Tensión Máxima Potencia (Vmpp)	39,18 V
Corriente Máxima Potencia (Impp)	8,98 A
Tensión Circuito Abierto (Voc)	48,82 V
Corriente Cortocircuito (Isc)	9,73 A
Eficiencia del módulo (%)	18,70
Tolerancia de Potencia (W)	0/+3%
Tensión Máxima del Sistema	DC 1000 V (IEC)
Backsheet	Negro
Coeficiente de temperatura de Pmpp	-0,41%/°C
Coeficiente de temperatura de Voc	-0,33%/°C
Coeficiente de temperatura de Isc	+0,06%/°C
Corriente inversa máxima	15A
Temperatura NOCT*	45+/-2 °C

Pérdida de carga

Caída de presión: *T* max:* 20,13 °C / *T* min:* 19,39 °C

29,88 l/h	0,002246 m.c.a.
65,88 l/h	0,006607 m.c.a.

Especificaciones Térmicas

Rendimiento óptico	0,7
Coef. Pérdidas Térmicas,a1	5,98 W/m².K
Coef. Pérdidas Térmicas,a2	0,00 W/m².K²
Volumen liquido interior	1,78 L
Temperatura de estancamiento	126°C
Num. Conexiones hidráulicas	4 conexiones
Medida Conexión hidráulica	conexionado rápido
Presión máxima admisible	10 bar
Caudal nominal	60 L/h

CE Conforme a las Normas de Producto:
IEC 61215 Ed2; IEC 61730-1,-2:2004;
EN 12975-1:2006 + A1:2001 ; EN ISO 9806:2017
Reservado el derecho de modificaciones técnicas.

Con 10 años de garantía
25 años de vida útil

Figure II.IV: Abora solar hybrid panel datasheet